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THE ROLE OF METEOROLOGICAL SATELLITES IN TACTICAL BATTLEFIELD WEATHER SUPPORT

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Final Report
(23 June 1981 - 28 Feb 1982)

17 March 1982

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AIR FORCE GEOPHYSICS LABORATORY
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The requirements for tactical battlefield weather support are examined and the critical area of mesoscale analysis and prediction is identified. Ground data processing techniques and personnel training requirements are assessed as well as current and proposed meteorological satellite sensors and systems. The minimum requirements for the Battlefield Weather Observing and Forecasting System are established. Report is fully documented and extensive reference list is included.

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TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

INTRODUCTION

Development of sensing and guidance systems has progressed as complex electronic components have become smaller and cheaper. Now it is possible to put into a football-sized package a complete television camera and a complex computer capable of analyzing the TV image to remember a designated object and to control a missile to impact that object. It is possible to package an extremely sensitive heat detector, an "eye" sensitive to only the light from a particular laser, a sensor that sees at microwave radio frequencies, or a tiny radar set to replace the TV camera. Each of these sensors, combined with their specialized electronic logic, can guide munitions to their targets with great accuracy. Precision Guided Munitions (PGM's) are expensive by comparison to "dumb" bombs and rockets, but, when they work well, they are highly cost effective. With PGM's operating well the AF has an effective tactical warfare capability. Without the ability to use PGM's effectively the United States could find itself unable to respond to an aggressive threat without resorting to nuclear weapons. The importance of maintaining the ability to use PGM's effectively is of paramount importance to the Air Force and to the nation.

Good as PGM's are, they have their weaknesses. They require more maintenance and checkout to insure that only functioning systems are carried into combat. They are expensive. Currently, the factor most limiting the effectiveness of PGM's is uncertain knowledge of weather. Although all PGM's are vulnerable to some weather situations, they are not blinded by the <u>same</u> kinds of weather (except for severe storms). That is, if the weather situation over the target could be known accurately, then, in general, an effective PGM can be selected. That this is true is important because it means that the tactical warfare situation is not just weather sensitive, but that it is weather <u>information</u> sensitive. Accurate weather predictions can make a real difference because valid decision options exist.

The tactical mission sounds simple enough; find the target, then hit it with some munition. However, the job is greatly complicated by the actions of the enemy, by the perversity and limitations of one's own equipment, and, frequently, by the weather. A great deal of effort has gone into developing systems to obtain information about the location and disposition of enemy forces, and elaborate checkout and calibration facilities are in place to

insure the operational reliability of the PGM's. However, the capabilities of the Air Weather Service have not developed to meet the current needs of the Air Force and the Army in a tactical warfare situation (MAC SON 508-78). In this study we have tried to summarize tactical weather support requirements in terms of current meteorological technology, and to establish actions which, if taken, would provide an effective Battlefield Weather Observation and Forecast System (BWOFS). The role of meteorological satellites developed as an essential part of the overall solution as the study progressed. The contract work statement which directed this study specified that we:

> "Determine the utility of satellites as tools for measuring or deducing required weather variables over data-denied tactical battle areas and airspace in both a day and night context ..."

The study started out to be a rather narrow look at the technical capability to measure critical meteorological parameters from satellites, but it soon became evident that such a study would be of little value without establishing the utility of such measurements.

Satellites carry remote sensors which produce data from which it is possible to _infer_ meteorological parameters. Remote sensing, whether from a satellite or other vantage point, differs fundamentally from _in_ _situ_ sensing.

A thermometer measures the temperature of the air with which it is in contact. We are confident that we _know_ what the thermometer measures because the very definition of "temperature" is based on the reaction of a thermometer, and because we can read the measurement directly -- no other process is involved.

To obtain the temperature of a parcel of air from a satellite a multispectral radiometer views the total column of air from surface to space and produces a set of numbers representing the amplitude of the energy emitted at specific wavelengths. A numerical model which describes the current understanding of the energy emission and absorption of atmospheric gases is used to convert the radiometer data to temperature values. Note that there are three major factors involved in obtaining air temperature from a satellite:

1. The radiometer data
2. The current understanding of the physics of atmospheric gases
3. The numerical model and the computation process.

In general, the same situation exists for _any_ remote sensor system,

including radar, camera, telescope, etc. A satellite image shows a picture of clouds, but the meteorological information which can be inferred from the image about winds, convection, precipitation, fog, haze, air mass characteristics, pressure fields, etc., depends upon the current understanding of the weather phenomena involved, and on the technical competence and efficiency of the person or process used to convert the data into meteorological parameters.

It is not possible to "deduce the utility of satellites as tools ... " without considering the current level of knowledge about the weather involved, and without establishing the method and competence of the data processing system.

The primary purpose of this study is to establish the role which meteorological satellites can play in providing tactical battlefield weather support. It will be our contention that meteorological satellites are essential and fundamental to the required system if it is to be both effective and economical. However, it is also our contention that meteorological satellites cannot be utilized effectively in the milieu of the present Air Weather Service. That is, that presently available facilities must be augmented and attitudes which have been formed during the past three decades must be reoriented before effective tactical battlefield weather support can be provided. The required technical capability is readily available; what is needed is the organizational will and insight to use it. It is pointless to describe the measurements which satellite systems can provide, or even how to process them, without also examining the factors which may either prevent or enable their effective utilization. A discussion of the meteorological and functional context in which BWOFS must operate is contained in Addendum "A" to this report, titled, "Weather, Data, and Prediction in BWOFS." The reader is urged to read the requirements section which follows, and then turn to the Addendum and to read it carefully before proceeding with the rest of the report.

TACTICAL WEATHER REQUIREMENTS

Before we can address the problems of how to provide effective meteorological support to tactical air and ground forces we need to understand what is needed.

The requirements for meteorological information to support the Air Force's tactical mission derive directly from the characteristics of the weapon systems involved. A detailed discussion of weapons and tactics for their use is not

required in this report, but some basic information is necessary to understand why some weather elements are more important than others. Both Army and Air Force requirements must be considered since the AWS must satisfy both in the field. The needs of the two services in a tactical warfare situation, with the exception of special requirements for ballistics winds for the artillery, are very similar since both services are concerned with low altitude aircraft operations and ground vehicle movement. These requirements are constantly being re-evaluated as weapons or tactics change, but the discussion which follows should be specific enough for the purposes of this report. (For a more thorough presentation see Cottrell et al., 1979.)

The tactical mission remains the same even with the new weapons; first to find the target, second to hit it. The type and condition of the target, the capabilities of the weapon system, and the weather are the three factors which must be known and evaluated to determine the two critical numbers: Target Acquisition Range (TAR) and Lock-On Range (LOR). If the pilot has to get too close to find the target or to have his weapon lock-on, then he becomes too vulnerable. If he is misinformed about the target or the weather, or if he carries the wrong weapon, he will return unsuccessful or perhaps not return at all.

For example, PGM's that "see" in the infra-red part of the spectrum actually sense the difference in temperature between the target and its background. A tank with a hot engine can be seen and hit relatively easily, but a tank that is cold sitting in a copse of trees may be either warmer or colder than its surroundings, or the same temperature, depending on the recent weather history and time of day. If rain has been falling, the tank is probably invisible to IR. If the sky has been clear all night and the sun has been up for an hour or more, the tank will be colder than its surroundings. If the wind has been blowing, the temperature difference will be less. Knowing what the weather is is not enough. The recent history of the weather must be known to determine the inherent thermal contrast; hence the Target Acquisition Range.

The state of the atmosphere when the pilot arrives at the target determines how much infra-red energy can reach the sensor of his PGM. Fog and rain are nearly opaque to IR radiation. Even very humid air reduces the Lock-On Range dramatically, but dry haze, most smoke and dust have very little effect. For weapons which "see" in the visible range humidity is not a factor, but haze, smoke, and dust can make the weapon useless. Each PGM system has its own set

of weather weaknesses.

WEATHER ELEMENTS WHICH AFFECT IR SYSTEM PERFORMANCE

WEATHER ELEMENT	EFFECT ON INHERENT THERMAL CONTRAST	EFFECT ON IR TRANSMISSION
SURFACE WIND	MAJOR	NONE
WATER VAPOR (DEW POINT TEMPERATURES)	MINOR	MAJOR
CLOUDS/FOG	MAJOR	EXTREME
PRECIPITATION (RAIN, SNOW)	MAJOR	EXTREME
HAZE, SMOKE, DUST		
DRY (LOW RELATIVE HUMIDITY)	MINOR	MINOR
WET (HIGH RELATIVE HUMIDITY)	MINOR	MAJOR
	WEATHER AT AND PRIOR TO TOT	WEATHER AT TOT

Table 1 - from briefing, "Weather Effects on the Performance of Passive Imaging Infrared Systems" by Maj. Robert P. Wright Hq AWS/DOOF 3 Apr 81 (Time-over-target, TOT).

In general, weather information is needed at three command (decision) levels on a different time basis at each level. At the theater command headquarters, weather information is needed to support long-range planning, and the period of interest is beyond 24 hours in the future. At the wing level, or equivalent, mission planning (targeting, weapon selection, scheduling, generation of air task orders, etc.) requires weather forecasts 12 to 24 hours ahead. At the unit operations level (which may also be at wing headquarters) mission execution decisions (go/no-go, retargeting, diverts, immediate air requests, etc.) require weather information ranging from current observations to forecasts up to 12 hours ahead.

The meteorological factors of concern are much the same at each of the three decision levels since all decisions involve target acquisition and weapon delivery. However, the scale and required accuracy differ significantly at each decision level. These important differences will be discussed in greater detail later. In summary, the more important weather factors are:

1. CLOUDS. The amount of cloudiness, i.e., the extent of cloud cover, is needed since clouds are the most frequent, and probably the most serious limi-

tation to "seeing" at all sensor frequencies. The heights of the cloud base and top are required and the accuracy with which the cloud base need be known becomes more important the closer it is to the ground. Cloud type, number of layers, and the general weather situation causing the cloudiness are important to the meteorologist.

2. ATMOSPHERIC TRANSMISSIVITY. (See Cottrell *et al.*, 1979 for a more lengthy presentation.) The terms "path transmission" and "contrast transmission" are frequently used to describe the relative transparency of the atmosphere. The meteorological factor in both terms is atmospheric transmissivity at the spectral frequency of interest. "Path transmission" is concerned with the ability to "see" an emitting source such as an electric light. It can be defined as the fraction of energy from an emitting source remaining after traversing a particular sight path. It is related to atmospheric transmissivity as $T = \tau^P$ where T is path transmission, τ is atmospheric transmissivity over the spectral interval of the sensor, and P is the length of the sight path. Atmospheric transmissivity, τ, is defined as the fraction of incident collimated beam at frequency of interest remaining after passing through a unit thickness of the atmosphere. It is a measure of the energy lost by absorption and scattering by the atmosphere along a sight path. Of course, what is needed in the end is the Target Acquisition Range (TAR). Assuming the target can be considered a non-collimated point source, TAR is found from Allard's Law (Middleton, 1952)

$$R^2 = \frac{I\ T}{E_t} \quad \text{where,}$$

R = Target Acquisition Range

I = Luminous intensity of the target

T = Path transmission

E_t = Threshold of sensitivity of the sensor.

"Contrast transmission" is the term used where one is concerned with "seeing" a target which is illuminated along with its surroundings by the sun or other external source. In this case the target is "seen" because the difference in reflectance between the target and its background produces a difference in apparent brightness. The brightness-contrast is reduced by absorption and scattering just as in the case of the emitting target above, but is further reduced by light scattered into the sight path. This case is more complicated

to describe mathematically, but a relationship which has been used (Haig and Morton 1958) to determine TAR in the brightness-contrast case is:

$$\tau^{P} = \{ (\frac{\Delta r}{\varepsilon} - r_1) \frac{E_g}{L_h} + 1 \}^{-1}$$

in which:

τ = atmospheric transmissivity

P = length of the sight path (TAR)

Δr = reflectance difference between the two adjacent contrasting surfaces being viewed

r_1 = reflectance of the brighter of the two surfaces

ε = brightness-contrast threshold of the observer or detecting sensor

E_g = terrain illuminance

L_h = horizon luminance in the direction of view of the approaching pilot.

In both cases, the meteorological factor is atmospheric transmissivity. At longer wavelengths (IR and microwave) the "brightness" of the atmosphere itself, i.e., the radiance of the atmosphere at the frequency of interest (a function of temperature) must also be considered in determining both path and contrast transmission.

In the end, what is really needed is enough information to permit accurate determinations of Target Acquisition Range and Lock-On Range. Of all the tactical mission weather requirements these are probably the most important, but are also the most difficult to meet.

3. WIND. Knowledge about wind speed and direction is required in the largest scale to predict air mass and storm movement; in medium scale to predict local weather; and in small scale to predict ballistic trajectories, smoke, haze and dust movement, ventilation cooling, etc. From the surface to about 3000 feet (in the boundary layer) the accuracy and vertical resolution requirements are most severe (a vector every 500 ft to about 5 knot rms accuracy).

4. TEMPERATURE, PRESSURE, AND HUMIDITY. Temperature to about 1C, pressure to $\pm$ 2 or 3 mb and relative humidity to $\pm$ 3% are needed at the surface. All three are needed to 25,000 feet at accuracies and vertical resolution similar to that available now from dropsondes or weather reconnaisance aircraft.

5. PRECIPITATION. Both the occurrence and the accumulation of rain, snow, hail, etc., are needed. The rate of precipitation is important to determining TAR and LOR and the accumulation is needed to determine soil moisture and snow depth. The occurrence of thunderstorms, freezing rain, icing, and turbulence is required.

Weather and time-of-day sensitivities of the different types of PGM's and Target Acquistion (TA) systems are summarized in Table 2.

SATELLITE DATA SOURCES

General

Meteorological satellites operate in two orbits which have special characteristics advantageous to weather observation. Satellites of the Defense Meteorological Satellite Program (DMSP) and the National Earth Satellite Service's (NESS) TIROS program are placed in orbit at about 450 n mi above the earth in a plane a few degrees west of north, when viewed as the satellite is moving south-to-north. The plane of this slightly retrograde circular orbit precesses; that is, it rotates about the earth from west-to-east about one degree per day so that the angle of the plane to the sun remains constant as the earth moves in its axis around the sun. This is called a "sun-synchronous" orbit, and the special features of meteorological importance are: (1) each orbit of the satellite occurs at the same solar time, and (2) the entire earth is covered twice each day by the satellite's sensors since the orbit is nearly meridional.

The Geosynchronous Operational Environmental Satellite (GOES) operated by NESS; METEOSAT, operated by the European Space Agency; and the Geosynchronous Meteorological Satellite (GMS, also called Himiwara in Japan) operated by the Japan Meteorological Agency are all in orbit approximately 22,000 n mi above the earth in the plane of the earth's equator, rotating in the same direction that the earth rotates about its axis. The orbital period is 24 hours so that the satellites appear from the earth to be stationary over an equatorial subpoint. The advantage of this orbit is the fixed relationship which the satellite holds relative to the earth's surface.

The Russian Molniya satellite series, which apparently includes both communication and meteorological payloads, uses a highly elliptical orbit with a 12-hour period. The Molniya satellites are launched into an orbit plane inclined 50 degrees or more to the equator with orbit apogee located over the area of greatest interest. From the ground, the satellite appears to spend

PGM/TA System	Environmental Limitations	Time of Employment	System Resolution
Human eye Visible range TV	Clouds & Haze Haze & dry aerosols Sun angle Precipitation Light levels	Day (avoid dawn & dark)	High
Silicon Vidicon TV (visible & near IR)	Clouds & fog Haze & dry aerosols Sun angle Precipitation Light levels	Day and bright moonlight	High
Laser (IR)	Clouds (except very thin) Haze (short wave-length only) Absolute humidity (long wavelength only)	Day or night	Not Applicable
Infrared	Clouds (except very thin) Haze (short wave-length only) Absolute humidity (long wavelength only)	Day or night	Medium
Millimeterwave or Microwave	Heavy clouds Precipitation	Day or night	Low

Table 2. Major atmospheric and solar effects on Precision Guided Munitions (PGM's) and Target Acquisition (TA) systems. (From Cottrell *et al*. 1979)

most of its time "climbing" to apogee or "falling" slowly from that point and remains within sight of the ground area of interest for about 10 hours at the same time of day on alternate orbits. For meteorological satellites this orbit can provide nearly continuous daytime coverage over the entire Russian land mass with better angle of view of the northern portions than a geosynchronous orbit in the equatorial plane can provide. Processing the data from the Molniya satellites must be a difficult task, however. There seems to be no interest in operating U.S. weather satellites in the Molniya orbit.

Other satellites with sensors capable of producing data of interest to meteorologists have been orbited such as NIMBUS, LANDSAT, and SEASAT. However, they are either one-of-a-kind developmental satellites or, like LANDSAT, produce data which are useful to meteorologists only for research. They will not be considered further in this report.

Within each of the two types of meteorological satellites (usually the DMSP, TIROS group is called "polar-orbit" and the GOES, METEOSAT, GMS group is called "geosynchronous"), the characteristics of the satellites and the sensors they carry tend to be similar. The DMSP and TIROS programs have been encouraged to work toward common equipment designs and to operate their satellites in close coordination so as to reduce the national polar-orbit system costs. The basic designs for METEOSAT and GMS were derived from the GOES design. and the three systems operated in cooperation during 1979 in the U.N. sponsored Global Atmospheric Research Program. Each program has its own peculiarities, however, which are discussed further below.

Both classes of satellite systems produce data in image format and also measurements which, usually after considerable processing, are interpreted as discrete quantitative values of meteorological parameters such as temperature and water vapor. Image data are collected in several visible and infra-red parts of the spectrum, and they are processed to produce both qualitative and quantitative information.

The special advantages of meteorological satellite systems include:

a. Global coverage of polar orbit satellites.

b. Spatially continuous data without the gaps common to surface observations, including radar.

c. Homogeneous data obtained from a single sensor throughout a complete data set;

d. High horizontal data density; hence high horizontal resolution.

e. Frequent observations from geosynchronous satellites; hence high temporal resolution.

f. Remote sensing radiometers inherently integrate over a surface area or through an atmospheric volume, thus producing a data set uniformly representative at a particular scale and free from the sampling noise produced by small scale characteristic of in situ sensors.

g. Real-time data collection is possible over large areas when either polar or geosynchronous orbit satellites are within view of a receiving station.

h. Simultaneous parallel reception of data by more than one ground station provides a high degree of communication link reliability.

i. Satellite-to-ground data links are difficult to block by intentional interference (Gruetzmacher 1982).

j. Satellite systems provide data at very low cost per bit or per observation.

k. Image data from satellites provide a wealth of qualitative information to a trained meteorologist without further processing.

l. Consecutive images from geosynchronous orbit satellites provide both qualitative and quantitative information about cloud dynamics; hence atmospheric circulation.

However, there are also disadvantages or shortcomings encountered in the use of satellite systems:

a. The data from polar orbit satellites is non-synoptic; hence there is a time-skew in data from a single pass and a discontinuity between passes. Even geosynchronous satellite images (from current systems) have a time-skew from top-to-bottom of the image which may be important when combining data from surface sensors.

b. Radiometer data require fairly elaborate computer processing to transform them into weather parameters which can be combined or compared with those obtained from conventional sensors.

c. Analysis of image data requires much subjective interpretation. A notable exception is the AFGWC Nephanalysis which is automated.

d. When a satellite fails the source of a very large volume of data is interrupted and the impact on a service which depends heavily on satellite data can be severe.

e. Satellites are expensive and as systems mature and sensors become more sophisticated, the satellites have become very expensive; hence, fewer are being built and the data gap between failure of a satellite and launch of its replacement tends to grow.

f. The volume of data from satellite systems is large, and extraction of just the portion of interest can be a nuisance; however, more recent data handling systems have reduced this problem considerably.

g. Data from satellites are hostage to the laws of orbital mechanics. It is not possible to make a polar-orbit satellite hover over a battle area, no matter how much it is desired.

h. It is relatively easy to provide high horizontal resolution in both radiometric and image data from polar orbit satellites, but it is much more difficult to provide equivalent temporal resolution. To provide resolution in time equivalent to the spatial resolution (1/3 n mi) of the DMSP images would require about 140 satellites; that is, a new observation every five minutes.

i. The quality of data collected from geosynchronous satellites diminishes rapidly at distances greater than about 65 degrees earth angle from the satellite subpoint. That is, the viewing angle from the satellite to the earth's surface becomes too small; hence, it is not good practice to depend on geosynchronous satellite data at latitudes above about 65 degrees.

In addition to the advantages and shortcomings which characterize satellite systems in general, each system has its own peculiarities. The discussion that follows is not intended to explore every detail of each system since that kind of analysis is well beyond the resources avilable for this study. The appendices include many of the numbers which define sensors and satellites more closely. What follows is a critical evaluation of what the current (and some proposed) satellite systems can provide to the BWOFS, with emphasis on the mesoscale, short-term forecast capability.

While reading about the several existing meteorological satellite systems one should keep in mind the current AWS policy statement:

"Meteorological Satellite (METSAT) policy. Satellites have proven to be a vital source of data for AWS support to national defense. The AWS objective is to provide every AWS unit having forecasting or briefing responsibilities access to satellite data applicable to their mission. The Defense Meteorological Satellite Program (DMSP) and other Department of Defense (DoD) controlled systems are AWS's primary sources of satellite data. Non-DoD controlled United States systems are AWS's secondary source of satellite data, and foreign systems are tertiary sources. These non-DoD controlled systems will be used to complement and supplement the DMSP. Hq AWS will program AWS units to receive satellite data; unit documented requirements will be satisfied based on mission priority, data utility, and cost." (AWS-CMP 1982-1996, 1982)

That section of the AWS policy document concerned with the use of meteorological satellite data states:

"Satellite data will be used by AWS to help satisfy worldwide military environmental support requirements.

"a. Timely satellite data are of immense value for target point assessments and short-range area forecasts. These data are observations of conditions which can change rapidly; large delays between data take and data receipt significantly degrate their operational value.

"b. When briefing air crews, command and control agencies, and others, satellite data provide instant credibility to the forecaster's assessment of the current situation, promote the customer's confidence, and enhance the decision process.

"c. AWS will also use satellite data in lieu of more expensive or less reliable conventional data sources; for example, to reduce the number of weather reconnaissance sorties or to reduce the impact of the loss of conventional data.

"d. Satellite data are not self-explanatory; they are most useful when blended with other available data and interpreted by a meteorologist. Therefore, AWS personnel will normally be available to interpret the data, provide the forecast, and insure the customers correctly use the data.

"e. A unit must have the techniques and training to exploit satellite data. Hq AWS will insure techniques and training programs are developed and used by AWS units. AFGWC is responsible for developing and employing techniques unique to their operation.

"f. Finally, AWS units will follow DoD established procedures for distributing DMSP data to non-DoD agencies/persons."

Polar Orbit Systems

Defense Meteorological Satellite Program

The actual origins of the DMSP are still shrouded in official secrecy for reasons which must satisfy some need - imaginary or real. There is no doubt that the USSR was able to determine the purpose of the first, and of all subsequent military meteorological satellites since only weather satellites use the approximately 400 n mi (740 km) sun-synchronous orbit.

The DMSP satellite has grown in size, weight, and complexity with each succeeding procurement. The inevitable consequences have been diminished reliability and increased costs. An unofficial estimate of the current cost of placing one DMSP satellite in orbit was given by a responsible program office member as being approximately $100 million! The danger is that DMSP may price itself out of the DoD budget and out of BWOFS regardless of how valuable its data might be. The past few years have demonstrated that the Air Force is willing to let procurement of high cost DMSP satellites and their boosters fall

behind the rate needed to replace those that fail in launch or on-orbit.

The sensors which DMSP satellites carry include several which measure ionospheric scintillation, auroral electrons and nuclear debris, but these are of no interest to BWOFS and will not be discussed further in this report. The primary meteorological sensor in DMSP is the Operational Linescan System (OLS) which was first flown in 1976 in the Block 5D series of spacecraft. Current program plans project continued use of the OLS without significant modification through the 1980s. The OLS has a good on-orbit reliability record, and it produces excellent images. It is a "back-and-forth" scanner with sinusoidal rate which virtually eliminates image foreshortening across the scan. That is, the images are not compressed at the edges as they would be with a linear or "round-and-round" scanner. Rather simple tricks with mirrors and switches also keep the scans parallel to each other and keep the size of the area covered by the sensor nearly constant at all times. IR and visible data are collected simultaneously by one optical system so the two images have identical geometry -- an important factor when the images are superimposed, compared, or manipulated in other ways in a man-computer interactive system.

The high accuracy attitude control system maintains the OLS axis within 0.01° of true earth vertical. Three gyroscopes sense short term attitude changes and a star sensor provides long term correction to limit gyro drift. Error information is interpreted by an on-board computer, and the platform holding the OLS is moved relative to the main spacecraft to hold the OLS within the 0.01° limit. This very precise pointing control (within 480 feet on the ground for a sensor with a 1800 ft spot size) does produce image data with high geometric integrity, but it does not provide the data user with information about where the data were collected. Locating the data in earth coordinates is accomplished at GWC by the computer which maintains the satellite ephemeris and simply assigns position along and across track as the data are received. The same system is used for both DMSP and TIROS images. Accuracy of location is within $\pm$ 3 n mi ($\pm$ 5.6 km) (Adams 1982) which is adequate for GWC use since DMSP image data is smoothed to 3 n mi resolution as it enters the computer data base (TIROS-N data are entered at 2.2 n mi (4 km) resolution).

At the GWC and at the Transterms higher resolution images (0.3 and 1.5 n mi) are analyzed only in photographic hard copy. Positioning is by using time along track to find the subpoint from the ephemeris and by measuring distance across track. Transparent overlays based on a nominal 450 n mi (833 km) circular orbit are used to position earth coordinate grids. Accuracy of position determined by this method is probably no better than $\pm$ 3 n mi and could be much worse since placement of the overlay is a poorly controlled part of the process.

More accurate positioning is possible by adjusting the location determined from the ephemeris with a landmark location. This process is easy and rapid when the images are available in a man-computer interactive system. For mesoscale analysis, accurate location of satellite images is necessary for combining data from radar and surface observation. However, data location to a level of precision matching that of the OLS pointing system is unnecessary.

The Precision Mounting Platform (PMP) with its star tracker, gyros, actuators, joints, etc., is the assembly which provides the high accuracy pointing of the OLS. The main DMSP spacecraft (and the TIROS-N spacecraft) is attitude controlled to 0.1^{o} by a set of reaction wheels controlled by horizon sensors and a sun angle tracker.* DMSP program office personnel estimate that the cost of the PMP increases the total spacecraft cost by about 20 percent. Several years ago, when the Office of Management and Budget was pressing the Air Force, NOAA, and NASA to combine the DMSP and TIROS programs into a single national polar-orbit meteorological satellite service, the requirement for extremely precise sensor pointing was defended vigorously by the Air Force. In fact, this was one of the major "irreconcilable" differences between the DMSP and NOAA requirements. It has been admitted for years by knowledgeable Air Force personnel in the DMSP program office, at AWS Headquarters, and at the GWC, that the high accuracy pointing capability is <u>not</u> required, and that it adds nothing to system effectiveness in either classified or unclassified missions. (Justification for this statement lies in over a dozen conversations with military and civilian personnel occurring over the past three years.) At present,

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* The DMSP Block 5D Compendium, Jan 1975 is the source of the 0.1^{o} attitude control capability. It should be noted that NOAA Tech Memo NESS 95, March 1978, specifies the capability of the Attitude Determination and Control Subsystem which both programs use to be $\pm$ 0.2^{o} (3σ) with information available to permit computation of yaw, pitch, and roll to 0.1^{o} by computer processing on the ground after the fact. The NOAA source also reports that with very few exceptions, the attitude is actually maintained within 0.12^{o}.

the PMP on Spacecraft F-4 has failed, and the OLS is controlled only by the main spacecraft system. At GWC and the Transterms, the F-4 data are handled exactly as though the PMP were working and there has been no loss of data value. Deletion of the PMP would reduce procurement costs and improve system reliability at no loss of useful capability.

Temperature and humidity profiles have been obtained by DMSP by a multispectral infrared sounder called Special Sensor H (SSH). This sensor produces data similar to that of the High Resolution Infrared Radiation Sounder (HIRS/2) on the TIROS satellites. The SSH horizontal resolution is less (2.7° field of view vs. 1.25° for HIRS/2) makes fewer soundings (ratio of about 1 SSH sounding per 12 from HIRS/2 over the same ground area), and has fewer spectral channels (16 vs. 20). There are two SSH flight units remaining; one will be on S-6, the next DMSP satellite to be launched, and the last will be on either S-7 or S-8, whichever is launched after S-6. The SSH is to be replaced by SSM/T, a microwave sounder.

A major weakness of the SSH has been the requirement for a four- to six-month on-orbit period to collect enough data to permit accurate calibration of the instrument before the temperature soundings were considered to be good enough for use at the GWC. Also, in the words of a GWC meteorologist, "The humidity profiles were not so hot." The SSH was not designed to produce data at the resolution required for mesoscale analysis, and the data have been reduced and used only in the GWC.

The SSM/T microwave sounder has seven channels in the 50-60 GHz band (50.5, 53.2, 54.35., 54.9, 58.25, 58.4, and 59.4 GHz center frequencies). A later model may include a 183 GHz channel for moisture measurement plus some on-board data processing, but this model is under study only at this time. The SSM/T is a cross-track nadir scanner with 14.4° field of view, $\pm 36^{\circ}$ scan angle, and 32 second scan period. It is obviously intended to produce data at synoptic scale. Nevertheless, AWS has requested the DMSP Program Office to provide the capability to process SSM/T data in the Mark 4 Transterms.

The SSM/T was first flown on F-4, a satellite which developed power problems early in its on-orbit history which required the SSM/T to be turned off. Several weeks of data were collected, but because F-4 was flown in an AM descending orbit instead of ascending, as was the previous practice, the SSM/T data were processed "backwards"; i.e., the data scans were reversed east-to-west. This error was not discovered until the sensor had been turned off,

so the SSM/T data received an unwarranted poor early evaluation. Post-analysis of the data by corrected procedures indicates RMS temperature errors of 2 to 3 degrees Centigrade (Arnold 1982).

A new sensor, a microwave imager, SSM/I, will be flown on S-9. This imaging system is a seven channel passive radiometer that scans cross-track at an angle of 45° from vertical over a 102° scan angle. Four frequencies (19.35, 22.235, 37.0, and 85.5 GHz) are sensed, with all but the 22.235 GHz band being sensed in both vertical and horizontal polarization to produce the seven data channels. The data will be processed to produce measurements of physical parameters as shown in Table 3.

Parameter	Geometric Resolution (goal)	Range of Values	Quantization Levels	Absolute Accuracy
Ocean Surface Wind Speed	25 km	3 to 25	1	± 2 m/s
Ice				
Area covered	25	0 to 100	5	± 12%
Age	50	1st yr, multiyear	1 yr, > 2 yr	none
Edge Loc	25	NA	NA	± 12.5 km
Precipitation over land or water	25	0 to 25	0, 5, 10, 15, 20 ≥ 25	± 5 mm/hr
Cloud water (> 100 μm dia)	25	0 to 1	0.05	± 0.1 Kg/m^2
Liquid water (> 100 μm dia)	25	0 to 6	0.10	± 2.0 Kg/m^2
Soil moisture	50	Dry - Saturated	1%	none

Table 3. SSM/I Product Descriptions (from Hughes Corp. briefing chart #96465-2).

Difficulties can be expected in achieving the objectives listed in Table 3, and these are discussed in a later section. If the objectives for the SSM/I are achieved, the information could be of considerable value to BWOFS. Even at the very low rate of four measurements per day, quantitative maps of precipitation,

cloud water, liquid water, and soil moisture can add very useful information. The capability to process SSM/I data may be included in pending modifications to the four Mark 4 Transterms.

Satellites through S-9 are on contract presently. A new procurement for S-10, S-11, and S-12 is scheduled for October 1982. All of these satellites are scheduled to be launched on expendable boosters, and the shuttle is to be used subsequently. All of the old "returned-from England" Thors are gone, and S-6 is to be launched on an Atlas. The booster is somewhat too large, but there are few alternatives and none cheaper. The move to Atlas has increased launch costs significantly.

Early in the Vietnam war the Air Force installed a readout station for the first military meteorological satellites at Tan Son Nhut Airfield. This station was hastily assembled from a discarded antenna reflector and a set of equipment which produced photographic hard copy of the images transmitted from the satellite's TV camera sensor. The pictures were rushed from the receiving station across the field to the weather station where they were treated as great novelties as first. After a few weeks it became routine to cut and paste the overlapping snapshots into strips, overlay a transparent grid for geo-reference, and then grease pencil in the synoptic analysis. As the Air Force expanded tactical operations, the forecasters became expert in picking out the mesoscale details of target zones, and the satellite images became a reliable and important data source.

The old scanning imagers which replaced the TV cameras greatly improved the usability of the DMSP product and provided good data both day and night. The old readout station was replaced by several Transportable Terminal Systems (TTS, usually called Transterms). These units included everything required to read out the DMSP image data and produce a strip of hard copy (positive transparency usually) in near real time. At the time the first Transterm was assembled, it was at the forefront of meteorological satellite data handling technology, but development of man-machine interactive video systems has left them far behind. A seagoing version of the Transterm has been installed in several US Navy vessels, and the Navy "adapted" the Transterm design, designated it the AN/TMQ-29, and placed several at ground installations around the world.

At present, the Air Force owns 12 Transterms procured on three contracts which are of nearly the same configuration. (16 Transterms were procured, but

evidently four were left in Vietnam.) All of these Transterms include an antenna, receivers, tape recorder, and equipment which produces a photographic hard copy -- either positive paper image or positive film transparency. The Air Force also procured four Mark 4 Transterms in 1978, three of which have been delivered. The Mark 4's have a video screen cn which a single frame of data can be displayed, and which can be altered by keyboard command to achieve different enhancements of the monochrome image. The enhancement developed on the display can be specified for the photographic transparencies. The equipment includes INTEL 8080 microprocessors which can generate latitude-longitude grids which appear on the hard copy. Ephemeris information is generated at the DMSP Control Center and sent to the Transterms, usually by mail, at intervals of a few weeks. This information is used to program antenna pointing and is the basic satellite location data for the grids. The basic data are updated by information which the satellite transmits with the image data. Grid location is about as good as is achieved in the older Transterms by using transparent overlays applied manually (about $\pm$ 3 n mi).

The AWS has requested modifications to the Mark 4 Transterms to correct a fairly long list of faults which were delivered with the units, and to include new capabilities to handle data from the microwave imager, SSM/I; the microwave sounder, SSM/T; and to receive and process WEFAX data from the GOES and Meteosat satellites. To date, no action has been taken by the DMSP program office in response to the AWS request, and no date has been established for the modification program.

TIROS-N Satellites

The latest in the TIROS series, the N model, was first launched in 1978. It uses the same basic spacecraft structure as the DMSP satellites, and they are built by the same company, RCA Astroelectronics. The TIROS and DMSP satellites use the same equipment for power, command, data recording and transmission, attitude control, and many other functions. They differ in sensors and the addition of a data encryption package in DMSP.

The satellites in the "N" series are designated (in order of probable launch) TIROS-N, NOAA-A, NOAA-B, NOAA-C, etc., through NOAA-G.

The advanced Very High Resolution Radiometer (AVHRR) is the visible and IR imaging system in TIROS comparable to the OLS in DMSP. The AVHRR is a five channel (versus two channels in OLS), cross track scanner with a $\pm$ 55.4° from

nadir scan angle, and field of view of 0.6 n mi (1.1 km) at nadir. While five channels are available in the instrument, some satellites operate in a four channel mode as shown in Table 4.

AVHRR Channel Assignments

Channel	TIROS-N	NOAA A,D,C,E	NOAA D,F,G
1	0.55 - 0.9 μm	0.58 - 0.68 μm	0.58 - 0. 68 μm
2	0.725- 1.1 μm	0.725- 1.1 μm	0.725- 1.1 μm
3	3.55 - 3.93 μm	3.55 - 3.93 μm	3.55 - 3.93 μm
4	10.5 -11.5 μm	10.5 -11.5 μm	10.3 -11.3 μm
5	repeat Ch. 4	repeat Ch. 4	11.5 -12.5 μm

Table 4. Spectral Characteristics of the AVHRR (From NOAA Tech Memo NESS 107, Nov 1979).

Data from the AVHRR are available from the satellite in four modes:

1. Direct readout to Automatic Picture Transmission (APT) ground stations at 4 km resolution of any two channels selected by NESS Control Center, usually channels 1 and 4). Panoramic distortion (crowding at the edges) is corrected in the on-board processor as the resolution is reduced from 1.1 km to 4 km.

2. Direct readout to High Resolution Picture Transmission (HRPT) ground stations at 1.1 km resolution of all five channels plus spacecraft telemetry and output of the TOVS subsystems described below.

3. Global coverage at 4 km of all five channels from on-board tape recorders at NOAA readout stations.

4. Readout of data recorded at 1.1 km resolution over selected locations at NOAA readout stations.

All Air Force Transterms and the GWC have been equipped to receive HRPT readout from TIROS-N satellites. However, when the capability was built into the Mark 4 Transterms only channels 1 and 4 were specified by the DMSP SPO; therefore, Harris added the circuits to prohibit channels 2, 3, and 5. The modification to the Mark 4's requested by AWS includes provision for all five channels. At the GWC and the Mark 4 Transterms, the panoramic distortion is removed by computer; at the Mark 1, 2, and 3 Transterms, it is partially corrected by making 24 linear approximations across the scan, using the same capacitor-diode circuits originally installed to correct the line-scanner images from the

DMSP Block 5-C satellites. Air Force forecasters who use the TIROS-N images have made the following observations:

1. The resolution of the TIROS-N images (0.6 n mi vs. 0.3 n mi for DMSP) is adequate for mesoscale analysis, but, given a choice, they would pick the DMSP images.
2. The TIROS spot size increases at the edge of the scan and the resolution there does fall off enough to be significant.
3. The four, or five, channels are a real advantage. Channel 3 is especially useful in discriminating clouds from snow from fog.
4. Both the AVHRR and OLS have advantages, and there is no clear choice. The best instrument would be a three- or four-channel OLS.
5. TIROS satellites fly at the wrong time of day to meet high priority data needs at the GWC.*
6. The GWC computer data base accepts both 4 n mi DMSP data and 2.2 n mi (4 km) TIROS data equally well.

The TIROS Operational Vertical Sounder (TOVS) is actually three independent sensor subsystems collocated so that they scan cross-track together. The subsystems are the High Resolution Infrared Radiation Sounder (HIRS/2), the Stratospheric Sounding Unit (SSU), and the Microwave Sounding Unit (MSU). Details of channel frequencies, scan angles, etc., can be found in the appendices. Data from the TOVS are used by GWC in the computer data base, but no capability exists to process TOVS data at any Transterm at this time. It is not clear whether or not the AWS request for Mark 4 Transterm modification includes TOVS data reduction capability. Evidently the careful prelaunch calibration procedures specified by NESS, daily calibration checks, and frequent updates of calibration values to users make it unnecessary to spend the first four to six months after launch in on-orbit calibration procedure as in the Air Force practice with the SSH sounder on DMSP.

Recent cuts in the NOAA and NASA budgets have eliminated the ongoing program for development of improved operational sensors for TIROS. It was planned to make a configuration change after eight satellites of the "N" series, probably in 1985. These plans have been abandoned, and it is now expected that the

* The solar angle (time-of-day) of each of the DMSP and TIROS satellites supposed to be operating in a four satellite array was determined by mutual agreement between AF and NOAA. DMSP satellites are supposed to operate at times of greatest interest to the AF.

current designs will persist through 1990, at least. There is concern held by some NESS personnel that a situation may be forced by budget restrictions which will require a choice between polar orbit and geosynchronous orbit satellite systems. Should this happen, it is most likely that the geosynchronous system would be chosen by the NWS, and in that eventuality, DMSP would stand alone. Plans for BWOFS should consider this possibility.

Geosynchronous Orbit Systems

Geostationary Operational Environmental Satellite (GOES)

The idea of a "spin-scan" imaging system on a satellite in geosynchronous orbit was first proposed by Dr. Verner Suomi in the mid 1960's. Two test models were flown on Advanced Technology Satellites (ATS-1 and 3) which proved the concept and provided useful data for over ten years. Two Synchronous Meteorological Satellites (SMS) were launched in 1974 and 1975 to provide initial operation experience, and these were followed by GOES satellites launched in 1975, 1977, and 1978, and the latest version of GOES with multispectral imaging and sounding capability was launched in September 1980 and March 1981. At present two GOES satellites are operated regularly, GOES-West at about 135° W longitude and GOES-East at about 75° West longitude. Both are the latest models with multispectral capabilities. Current status of the satellites is as follows:

SMS-1 Operable, but transmitter is noisy. Satellite is nearly out of gas and cannot adjust orbit or position, but attitude is still good. Not operating.

SMS-2 Also out of gas and deteriorating performance. Not operating.

GOES-A Visible channels in VISSR are okay. IR channels are bad. Communications capability okay. Not operating.

GOES-B VISSR inoperable, but rest of satellite in good condition. Currently located at about 100° W Long, and used as data relay satellite in "transparent MSI" operating mode described below.

GOES-C VISSR has serious problem. When mirror moves past critical point power short occurs; therefore, scan area is limited and operation threatens satellite. Not operating.

GOES-D First of the VAS units. Currently GOES-West.

GOES-E Second VAS unit. Currently GOES-East.

The satellite is an 800 pound cylindrical flywheel spinning at 100 rpm with its spin axis parallel to the earth's axis of rotation. The imaging telescope, the Visual and Infrared Spin Scan Radiometer (VISSR), lies along the

spin axis viewing a movable mirror which reflects the earth below at each rotation of the satellite. The telescope "sees" only a single spot (per sensor) which sweeps across the earth repeatedly as the satellite spins. At each revolution the mirror is tilted slightly and the spot scans a different part of the earth. After 2000 revolutions of the satellite the earth has been scanned from pole to pole. The image of the earth which GOES produces is free of optical distortion and is geometrically correct everywhere thanks to the great inertial stability of the spinning flywheel. This makes it possible to compute the exact latitude and longitude of each picture element (pixel) a day or two in advance, and when images are sequenced in motion picture fashion, the earth stands still.

There are eight visual sensors which scan the earth in parallel to generate eight lines of data during each satellite rotation or a total of 16,000 lines per image. In the older GOES, two IR sensors scanned in series to provide redundant IR images. In the new GOES the VISSR has been modified to the VISSR Atmospheric Sounder (VAS) and a more complex array of IR sensors plus a filter wheel allows images to be made in as many as three different IR channels and visible simultaneously. Also data may be collected in 12 spectral bands for sounding. Visible data channels are sampled 16,000 times per scan and IR 4000 times to produce ground spot image sizes of ½ x ½ n mi for visible and 4 x 2 n mi for IR..

GOES is actually a communications satellite system used by meteorologists. From geosynchronous orbit height the earth subtends an angle of about 18 degrees. The VISSR sensors are active for only 20 degrees out of each 360 degrees rotation of the satellite while they scan the earth. During that time ten data channels are transmitted simultaneously to the NOAA Command and Data Acquisition (CDA) station at Wallops Island, VA. At the CDA the data are processed through a Synchronous Data Buffer (SDB) which sorts out the ten lines of data; corrects for variations in satellite spin rate by making all lines have the same number of pixels; corrects data amplitudes in accordance with each sensor's calibration table; adds earth location grids and boundaries; and then sends the data out one-line-at-a-time, stretching the whole stream to fill the time that the satellite rotates 340 degrees to start the next earth scan. This stretched data stream is transmitted to the satellite which simply repeates it to all the interested data users. The bandwidth of the original transmission is about 40 times greater than that of the stretched data. At the CDA a 60 ft dia antenna is used, but

stations with only 12 ft dia reflectors can receive the stretched data.

Imaging takes 20 minutes of each half hour. During the remaining 10 minutes the GOES is used to relay WEFAX data and graphics and to perform a number of specialized functions. Over 1200 Data Collection Platforms (DCP's) of many types report either automatically or on interrogation through GOES to the CDA. Many of the DCP's are unmanned stations in mesoscale data collection nets, and they are examples of data collectors which could be used in BWOFS.

More details of GOES and its functions are available in the appendix.

The unique capability of the geosynchronous orbit satellites to view a particular region repeatedly at short intervals makes these satellites particularly valuable for mesoscale analysis. GOES normally images the whole earth disk each half hour, but it can be programmed to scan only a part of the earth more frequently. To support mesoscale analyses during particularly interesting episodes of convective activity, lengthy sequences of images at intervals as short as three minutes have been collected. Analyses of these images have revealed much new information about mesoscale phenomena (Peslan 1977, Purdom 1981).

During the PROFS 81 DRT, GOES images were used in man-computer interactive systems in combination with conventional data to make mesoscale analysis of several selected situations. A major finding, in which most participants agreed, was that the GOES images at half hour intervals were too infrequent. Intervals between three and 12 minutes were suggested with both the personal preference of the forecaster and the weather situation influencing the choice of interval (Small 1982).

The interval between images is important because it brings the temporal and spatial resolutions of the data into correspondence. Clouds or parts of clouds such as overshooting towers (Fujita 1974), arc clouds (Smith, D. 1979), dry lines (Miller 1979), etc., can be seen easily in satellite pictures, but only if the picture is made while these short-lived phenomena are present. The real power of satellite images can be realized when they are viewed as a motion picture sequence. The significance of "temporal resolution" becomes strikingly apparent when one can watch mesoscale events through their entire life cycles and see the interrelationship of phenomena of different scales as they interact.

By far the most important contribution which the geosynchronous satellites have made to meteorology has been to make it possible to access the time

domain, to be able to see the cloud systems in motion. This capability is useful at all scales, but most importantly at the mesoscale where meteorologists have never before been able to observe events clearly. The importance of being able to capture events in the time dimension as well as space, and to see the dynamics of the situation being analyzed, cannot be overemphasized. Much of the value of images from geosynchronous satellites is lost unless the analyst can access and manipulate the data in a responsive, flexible man-machine interactive system.

The VAS is technically still in an experimental status, but demand for the multispectral images and for the soundings has forced a combined operational/experimental mode of operation. At present both GOES-East and -West are VAS type satellites, but the CDA station has only one SDB capable of handling the VAS "AA" mode of operation (see appendix for details). Therefore, GOES-West operates in the old VISSR mode except twice each day when the IR image is switched from the 11 μm thermal window channel to the 6.7 μm water absorption band. This service has proven to be so popular that an official requirement for its continuance has been filed by the Western NWS regions. The water vapor image provides new information about air mass motion and characteristics, but its greatest value is in locating the upper level jet stream. Dry streaks bounding the jet show clearly in the water vapor image.

Meanwhile, at GOES-East, the satellite is being operated in VAS multispectral imaging mode most of the time, but the stretched data are sent up to the GOES-B satellite for relay to those having the capability to receive the VAS AA data. The visible and thermal window IR channel images are stripped out and relayed through GOES-East in the normal GOES A message format. To data users it appears that GOES-East is being operated in the old VISSR mode; hence, it is called a "transparent MSI" mode. Image scan times have been shortened to 18 minutes to provide 12 minutes for WEFAX transmission, dwell sounding, etc.

The National Hurricane Center in Florida and the NESS Development Group in the World Weather Building, D.C., will have interactive terminals operating remotely with the McIDAS at the NESS/SSEC laboratory where the VAS sounding data are now processed. These terminals will go into operation in May or June 1982. The Naval Weather Research Facility at Monterrey is modifying its equipment to receive the VAS "AA" mode and the basic capability is in place at AFGL (although it has not yet been completed nor used). The NMC and the Severe Storm Center,

Kansas City, are already receiving VAS sounding and image data on a regular basis. By mid summer, VAS sounding data will be in regular operational use in the NWS.

With the exception of the water vapor channel images noted earlier, little or no multispectral image data are available yet to operational forecasters. Research investigators report that the 3.7 μm channel provides excellent low level temperature information and in combination with the 11 μm window channel, provides a sensitive cloud detector which helps to eliminate cloud contamination errors in measuring sea surface temperature. The height of thin cirrus was measured accurately during FGGE by using two of the CO_2 channels and one window channel from TIROS. The same technique has been used with similar VAS image channels to map cloud top heights more accurately (Kahwajy and Mosher 1981). As part of the VAS experiment, rapid sounding scans of the entire U.S. have been made (about 12 minutes is required), and the data are processed to produce maps of relative vertical stability. While still experimental, the maps appear to pinpoint areas of probable convective activity with high resolution and good accuracy.

Meteosat (Europe)

The European Space Agency is a consortium of Western European nations organized to bring together European talent and resources in earth satellite and space exploration programs. Frequently called the NASA of Europe, it includes exploratory, research, and operational programs. ESA headquarters is located at 8-10 rue Mario-Nikis, 75738 Paris 15, France. The Meteosat program (by far the largest enterprise ESA has undertaken to date) was a major part of Europe's contribution to the First GARP Global Experiment (FGGE) of the Global Atmospheric Research Program (GARP). It is ESA's intention to maintain a Meteosat satellite in geosynchronous orbit at 0° longitude as an ongoing operational data source for all European and North African national weather services. The first Meteosat was launched 23 November 1977 and failed late November 1979. Meteosat 2 was launched June 1980 and is operating as this is written.

The Meteosat Ground Computer System (MGCS) is located in the European Space Operations Center (ESOC) at Darmstadt, Federal Republic of Germany. The Data Acquisition, Telemetry, and Tracking Station (DATTS) is located about 50 miles from Darmstadt. ESA facilities are manned by multinational teams.

The Meteosat satellite is about the same size as the GOES satellite and operates in much the same manner. The satellite is spin-stabilized at 100 rpm with the spin axis parallel to the earth's rotational axis. The imaging sensor is a 400 mm aperture telescope with 3650 mm focal length. Scanning is accomplished by stepping the entire telescope (versus a plane mirror as in GOES) 2500 times per image. Four channels of data are sensed. Two identical visible sensors (0.4 to 1.1 μm) split the field to provide 5000 lines per image when data from both sensors are used. The visible sensors are sampled 5000 times per line to provide nominal resolution of 2.5 km. One IR channel (10.5 to 12.5 μm) in the water vapor window provides temperature mapping similar to GOES at 2500 lines per image. A second IR channel (5.7 to 7.1 μm) in a water vapor absorption band provides mapping of upper atmospheric water vapor. The IR sensors are sampled 2500 times per line to provide 5 km nominal resolution. Any three channels can be read-out per image. Normally the IR window channel and either both visible channels or one visible and the IR water vapor channel are read-out. When the water vapor channel replaces one visible channel it is over-sampled at the 5000-per-line rate. All data are digitized at the sensor.

In normal operations the sensor data are buffered on-board and read-out at 166 kilobits per second. If the buffering subsystem fails, the sensors can be read-out directly at 2.7 megabits per second. On-board buffering replaces the rebroadcast operation of GOES. Broadcast to data users is at either 1691.0 MHz or 1694.5 MHz and to the DATTS at 1686.833 MHz.

Data are received at the DATTS on a 15 m diameter auto-track antenna and sent via a 1.3 MHz data rate ground link called the Data Transmission and Routing System (DTRS) to the MGCS. The Meteosat Control Center (MCC), collocated with the MGCS, contains the Meteosat Operations Control Center (MOCC), landmark consoles, and three consoles which make up the Meteorological Information Extraction Center (MIEC). Incoming data are recorded raw in a rotating tape archive and held until processing has been completed successfully. The goal (now routinely achieved) is to process all data in real-time (2×10^8 bits per half-hour). Optical errors, sensor calibration, filter compensation, line start errors, spin-speed correction, registration errors, etc., are all corrected in a Front End Processor (FEP) before information is extracted.

Images are navigated predictively to provide earth location. Landmarks

are used as primary source of location information. Satellite motion is detected by four earth-edge detectors (14-16.4 μm), two of which routinely scan the earth at each rotation of the satellite and provide pulses at earth-edge transitions. Sun-slit sensors provide a sun pulse each revolution for inertial reference, and two accelerometers give nutation amplitude and phase. Earth-edge and landmark data are input to a computer model which predicts deformation polynomials and matrices applicable up to two images (one hour) ahead. These matrices allow data users to transform image pixel location into geographical coordinates. Line start and scan threshold values are determined from the deformation model and fed to satellite control.

At the MIEC, operators at man-computer interactive terminals control the information extraction process. Both automatic computer routines and manually directed processes are used as appropriate. Products include cloud motion vectors, sea surface temperature, cloud analysis, upper tropospheric humidity maps, radiation balance data, cloud height maps, and others. Cloud analysis produces a map of cloud cover at several levels each six hours. Cloud height maps are transmitted via WEFAX in eight grey levels.

WEFAX images and numerical weather data are relayed via Meteosat at the two data users S-band frequencies (1691.0 and 1694.5 MHz). The WEFAX data format is the same as that transmitted by GOES and nearly the same as sent by the Japanese GMS system.

Meteosat has 66 Data Collection Platform (DCP) receiving channels in the UHF (400-470 MHz) and VHF (137-149 MHz) weather operations bands. DCP readout is to the DATTS.

The AWS has requested the DMSP program office to modify the four Mark 4 Transterms to provide the capability to receive the Meteosat WEFAX transmissions. We understand that it is possible to receive Meteosat transmissions at the east coast of the U.S., and that the capability to do so has been demonstrated at the NOAA Wallops Island, VA facility. However, there is no regular distribution of Meteosat data in the U.S.

Geostationary Meteorological Satellite (GMS) (JAPAN)

The Japan Meteorological Agency (JMA) sponsored and operated the GMS as part of the First GARP Global Experiment (FGGE). The GMS satellite is similar to GOES and the sensor, Visible and Infrared Spin Scan Radiometer (VISSR), is nearly identical to those used by GOES.

The GMS VISSR operates with four visible (0.5 to 0.75 μm) channels per scan (instead of eight in GOES) to provide 1.25 km nominal resolution. One IR sensor (10.5 to 12.5 μm) per scan provides 5.0 km resolution. An image is made up of 2500 scans, one per revolution of the spin-stabilized spacecraft which rotates at 100 rpm. The visible sensors are sampled 10,000 times per scan and the IR 2500 times. The VISSR optic is a reflective telescope with 40.6 cm aperture and 291.3 cm focal length.

The VISSR data down link is centered at 1681.6 MHz with ± 10.1 MHz deviation. Data are received at the Command and Data Acquisition Station (CDAS) where they are processed in a Synchronizer-Data Buffer (SDB) (nearly identical to that used by GOES) to stretch the data before it is sent by microwave link to the Meteorological Satellite Center (MSC) located about six miles away. Note that the VISSR data are not immediately transmitted in stretched form to the satellite as they are in GOES. Instead, the SDB transmits the processed data from the MSC derived from earlier images.

At the MSC two production data processing systems, each with two FACOM 230-75 computers, are operated separately as an on-line system and a batch system. The on-line system makes image projection conversion from the original satellite image to whole-disk earth pictures, polar stereographic pictures, mercator projections, and a set of earth sector images. The batch system receives the processed data from the on-line system and produces maps of cloud top height, sea-surface temperature, and upper air winds. Technicians from JMA spent several years with NESS, GSFC, and the SSEC at the University of Wisconsin learning how these groups processed ATS and GOES data before they designed their system. The result was a frequently incompatible mixture of techniques, including film strips for image sequence animation, a man-machine interactive display of severely limited capability for cloud motion work, and a mixture of analog and digital manipulations to approximate earth location. During FGGE operations JMA learned much about the faults of their system, and they have been changing the hardware and software on a continuing basis to improve the quality of their products. They have upgraded their man-computer interactive system by providing larger computer capacity. Cloud winds used to be obtained automatically by computer and then edited on the man-machine console; now the computer is used less and the man more; navigation of the image data is now done by the SSEC method.

The first GMS satellite produced images which were nearly impossible to navigate precisely because the scanning mirror was not properly balanced and changed the moments of inertia of the satellite during each picture-taking operation. This caused the nutation of the satellite spin axis to change in a complex manner which was difficult to predict. Also, the satellite was troubled by an anomalous, unpredictable, recurring disturbance thought to be caused by fuel sloshing which could perturb the VISSR pointing axis as much as seven data lines. The JMA personnel did an outstanding job in correcting the images to the maximum extent possible, but as soon as GMS-2 was launched in the fall of 1981, the first satellite was retired to stand-by status. The problems appear to have been fixed on the second satellite.

Comparisons of cloud motion winds obtained by JMA from GMS and those by ESA, NESS, and SSEC for FGGE were performed by Mosher (1982). In general, the individual GMS vectors were about as good as those measured elsewhere, except for a consistent bias in cloud height determination. JMA wind sets exhibited a more serious problem. The clouds to be tracked were selected from a single image (the JMA interactive display has only one refresh frame), and the operator had no information about cloud motion; therefore, on several occasions the clouds selected produced wind patterns which missed major circulation features. For example, clouds were tracked on only one side of a trough; hence, the trough was missed entirely. This experience illustrates how important it is to provide adequate data processing equipment to the analyst.

Nephanalysis and synoptic scale air mass analysis is done on large photo enlargements and on film strip projections. These and the other products are sent through the SDB to the GMS for retransmission to data users. JMA has tailored the retransmission program to meet as many of the diverse needs of the Southeast Asian countries (Australia, Phillipines, and the Western Pacific Islands) as possible. Transmissions are based on a three-hour cycle, and are made in facsimile formats compatible with the TIROS APT and HRPT systems. Characteristics of the stations capable of receiving the two types of transmission are shown in Table 5.

	MDUS (HRPT)	SDUS (APT)
Receiver		
Frequency	1687.1 MHz	1691.0 MHz
Modulation	FM/FM	AM/AM
Bandwidth	1 MHz	26/260 k Hz
G/T incl. antenna	10 dB/^{o} K	2 dB/^{o} K
Antenna		
Type	4 m parabolic	2.5 m parabolic
Gain	34.8 dB	30.7 dB
Beam width	3 degrees	4.8 degrees
Recorder		
Type	Laser Fax	Laser fax or Electrostatic
Index of Coop.	2000	268
Drum rate	400 rpm	240 rpm
Receiving time	12 min/pic	3.5 min/pic

Table 5. Characteristics of Medium- and Small-scale Data Utilization Stations (MDUS and SDUS) for GMS products.

Further details of GMS retransmitted products, schedules, etc., can be found in the appendix. Some GMS products are now available within the U.S. from the NESS operated GOES data distribution service.

SATELLITE INPUT TO BWOFS

The rest of this report is a very brief summary of what meteorological satellites can contribute to an effective BWOFS. Emphasis is on mesoscale analysis and prediction, but this should not be interpreted as a slight to the importance of analysis and forecasting at synoptic and global scale. Providing good information and forecasts in the 0 to 12 hour period appears to be the major problem area since the GWC is already doing a creditable job at the larger scales. It would be difficult to overstate the importance of meteorological satellite data to GWC operations, but the facts in this area are already documented and are demonstrated daily; therefore, the limited resources available for this study have been focused on the mesoscale.

In order to discuss the role of meteorological satellites in BWOFS it is necessary to assume that adequate capabilities will exist in BWOFS to utilize the satellite data effectively. The following key elements of BWOFS, which may

be considered to be design recommendations, are assumed:

1. The mesoscale analyses and forecasts, 0-12 hour period, are to be made by combat weather teams (WETM) located with the Wing Operations Center (WOC) which each serves. That is, that the shortest-term, fastest-response weather service is to be decentralized.

2. Synoptic scale analyses and forecasts are to be made at more centralized weather facilities located at Tactical Air Control Center (TACC) or even at the GWC.

3. AT the WOC the WETM will be equipped to readout and process data from both polar orbit and geosynchronous orbit meteorological satellites, as well as any other weather data sources which may exist in that WOC's area of interest. Other data sources could include manned or automatic observing stations, pilot reports, radars, etc.

4. The data processing equipment for the WETM includes a man-computer interactive system with several (3-5) forecaster stations. This system will have display and high speed data manipulation capabilities equal to or greater than those of the current McIDAS or CSIS systems.

5. The WETM data handling system will include the computer capacity to run small specialized mesoscale forecast models such as advection extrapolation, boundary layer mixing, dynamic instability and convection, etc., with provision for future growth to accommodate more advanced mesoscale models as they become available.

6. Analysis and prediction will be done by forecasters well trained and experienced in the use of the man-computer interactive system. Forecasts will be made by subjective interpretation of thorough dynamic mesoscale analysis augmented by objective models when available and when appropriate. Increasing use of mesoscale models should be anticipated, but the forecaster at the console should remain in full control.

7. Each WETM will be equipped and fully competent to provide adequate tactical battlefield weather support to its WOC without outside assistance for several days if necessary. That is, the "fall back" capability will be the fundamental capability. Data and products from other WETM's and from central facilities will be available when communications are functioning, but the WETM need not depend on them.

While these assumptions may not agree with others' concepts of BWOFS, they are achievable and conservative. Equipment costs are not excessive (about $250,000 and a Transterm per WETM) and decentralized operations are more survivable. These assumptions are stated here because what satellite data (or any data) can contribute to BWOFS depends upon what BWOFS can do with the data.

Images and Clouds

Meteorological satellite images are pictures of clouds primarily; and some other atmospheric and terrestrial features can also be seen. The literature on analysis of clouds in satellite images is extensive and still growing. As might be expected, the earlier publications are concerned for the most part with synoptic and global scale events, while the more recent literature treats either mesoscale analyses or climatological information. It would serve no purpose to repeat, even briefly, the content of the excellent cloud analysis handbooks and reports which have been published. A partial list of such references is:

BITTNER, F.E. and K.W. Ruggles (1970): Guide for Observing the Environment with Satellite Infrared Imagery. NWRF F-0970-158, Project FAMOS, Naval Wea. Res. Fac. Hillcrest Heights, MD. 478 p.

ANDERSON, R.K. and N.F. Vestischew (1973): The Use of Satellite Pictures in Weather Analysis and Forecasting. WMD Technical Note No 124, WMO No. 333, WMO, Geneva. 275 p.

ANDERSON, R.K., J. Ashman, F. Bittner, G. Farr, E. Ferguson, V. Oliver, and A. Smith (1974): Applications of Meteorological Satellite Data in Analysis and Forecasting. NESS Tech Rpt NESC 51. (Previously issued Sep 69, supplement #1 Nov 71, supplement #2 Mar 73; also issued as AWS/TR 212). Natl. Environmental Sat. Cent., Washington, D.C. Mar 1974.

AWS TR-74-250: DMSP User's Guide. December 1974. Hq AWS, Scott AFB, IL.

BRANDLI, H.W. (1976): Satellite Meteorology. AWS/TR-76-264 USAF, AWS, Scott AFB, IL (NTIS No AD-A067090). 203 p.

AWS/TN-79/003. Satellite Applications Information Notes Oct 1975-Dec 1978. Prepared by NESS and NWS Aug 79. Hq AWS, Scott AFB, IL.

ESA SP-143 (1979): PROC Techn. Conf. on Use of Data from Meteor. Sat., Lannion, France, 17-21 Sep 1979.

ESA SP-159 (1980): Satellite Meteorology of the Mediterranean Proc. of the Intl. Sch. of Meteor. of the Mediterranean. Erice, Italy, 12-22 Nov 1980. 314 p.

ESA-SP-165 (1981): Nowcasting: Mesoscale Observations and Short-range Prediction. Proc. Intl. IAMAP Symp. 25-28 Aug 1981, Hamburg, Germany. 415 p.

Clouds in satellite images are both objects of interest in their own right and also indicators of atmospheric circulation and moisture distribution. The references cited give ample evidence of the ability of an experienced analyst to identify types of clouds, to classify them as high, middle, or low, to determine percent of sky cover with good accuracy, and to infer much about the air mass in which the clouds are found. Schemes for objective cloud classification have been proposed (Shenk et al. 1976), but there does not appear to be any value in using automated cloud classification in BWOFS -- this being a small part of a mesoscale situation analysis.

Cloud top height is usually inferred from the temperature measured by the imaging IR sensor. Errors are caused by clouds too small to fill the field of view of the sensor, clouds thin enough to let the sensor "see through" them, temperature ambiguity caused by lapse rate inversions especially at the tropopause. (See Suchman et al. 1981 for latest techniques and evaluations.) Tops of clouds free of problems listed above can be determined operationally to about 2 km. Cloud top heights have been measured very accurately (0.1 to 0.5 km) by stereographic observations from two geostationary satellites (Hasler 1981).

Cloud base heights cannot be measured directly by any satellite system. No proposals for a cloud base height measuring sensor are known to the author. It may be possible to generate a cloud base height with a mesoscale numerical prediction model, but no evidence of such an attempt was found in the course of this study. The most reliable method used during GATE was to find the condensation level from radiosonde data in the absence of a direct height measurement (Suchman et al. 1981).

As indicators of atmospheric circulations, clouds have been studied for centuries. The references listed above show hundreds of examples of how to interpret cloud patterns to deduce the air motions which caused them. Most of the examples are of synoptic scale events, but many treat mesoscale phenomena. AWS Tech Note 79/003 is a collection of mesoscale analyses. Fujita (1981 a and b), Purdom (1971, 1973, 1974, 1976, 1979, 1981), Maddox (1977, 1980), and many others have filled the journals and conference proceedings during the past decade with articles describing mesoscale analyses using satellite images. Some of the techniques and results of their studies are noted below in discussions of specific phenomena of particular interest to BWOFS (fog, soil moisture, precipitation, etc.), but this report cannot begin to review all that has been

learned about how to use satellite images in mesoscale analysis. Purdom (1979) summarized the importance of satellite images in these words:

> "Satellite imagery must become the basis for future studies concerned with the mesoscale evolution of deep convection. Other data sources must be organized and interpreted based on the imagery."

Mesoscale analysis and prediction systems which are being developed all use man-machine interactive displays to combine data from all available sources. Almost without exception, the analysis process starts with a series of satellite images and other data are added in the satellite image format. Dr. Purdom's observation appears to be accurate.

Atmospheric Transmissivity

Dr. James Gurka, NESS Applications Division, has made a career of finding fog and forecasting its formation and dissipation. His publications (Gurka 1974, 1975, 1978a, 1978b, 1980 are examples) are the definitive word on fog and stratus. In his words (1980):

> "Geostationary satellite imagery has become an indispensable tool for observing and predicting fog dissipation and formation. Visible imagery shows the fog boundaries and how they dissipate during the daylight hours, while the infrared imagery shows the fog boundaries 24 hours per day. Although the fog boundaries are usually not as obvious in the infrared as in the visible, with the use of image animation and a proper infrared enhancement, the formation of advection-radiation fog can often be detected on the infrared image..."

Atmospheric turbidity was determined from satellite data by McLellan (1971, 1973) by measuring the change in reflected earth radiance over Los Angeles during a day. Turbidity caused by desert dust over the Atlantic was measured from GOES data during GATE (Norton et al. 1980) and from poalr orbit data (Carlson 1978).

A different and potentially more useful technique measures the contrast reduction by atmospheric haze by viewing a "two halves" scene (Mekler and Kaufman 1980). This method does not require precise calibration of the sensor and is relatively independent of the phase function of the obscuring aerosol and even of the type of aerosol. To use this technique, two adjacent areas of different reflectivities with a fairly sharp boundary between them must be found -- areas such as a shoreline, a lake, a large river, a forest next to a pasture, or a mountain's shadow; all would do. Two sets of images are required, one on a clear day (for reference) and one when the turbidity is to be measured. The rest is a relatively simple calculation (Kaufman and Joseph 1982).

There appears to be no reason why the "two halves" method would not work equally well to measure water vapor if the scene were viewed in an appropriate spectral band.

Both techniques can be used only in cloud-free areas, of course.

Wind and Cloud Motion Vectors

Air motions can be deduced by analyzing static snapshots of the cloud patterns. Streamline analyses of large storms are made this way regularly at GWC. Such analyses help complete the global weather picture over areas where there is little other data. Mesoscale analyses can be made in the same way and important meso-features can be defined and located. A good presentation of the processes which have been developed at GWC to analyze single images and to infer wind fields is given in AWS TR-76-264 (Brandlii 1976).

While a surprising amount of very useful air motion information can be obtained from a single image by an experienced analyst, there is no doubt that cloud motions can be appreciated far better when a series of images can be viewed in sequence as a motion picture. Accurate measurements of cloud motions can be made from such a series when they can be accessed in a man-machine interactive system. Synoptic scale cloud motion measurements are made routinely from images from all three geosynchronous satellite systems by ESA, NESS, JMA, ANMRC, and other national weather agencies. Many research groups measure cloud motions for studies ranging from case histories of individual clouds to the global wind fields for FGGE.

Again, cloud motion measurements are made best using a man-machine interactive system. Attempts at fully automated cloud-wind measuring schemes have been made (Fea 1980, Sitbon 1980, Kodaira et al. 1979, Bristor 1979, Leese et al. 1971, Nagle and Lee 1979), but in every case the fully automated mode has been augmented or replaced by one which permits an experienced analyst to pre-select clouds to be measured, or post-select vectors to be rejected, or both. The requirement for human intervention stems from the complexity of the cloud patterns, the fact that not all clouds are good air motion indicators, and the difficulty in determining the height which should be assigned to a cloud motion vector.

Selection of clouds to track requires experience and a sound knowledge of cloud dynamics. The time interval between pictures in a sequence is important in determining which clouds can be tracked. In general small cumulus are good

tracers (Hasler et al. 1977), but the size of the cloud must be several times larger than the field of view of the satellite imager and the cloud must persist long enough to appear relatively the same size in three successive images. Orographic clouds and clouds caused by gravity waves do not move with the winds, so they should not be selected. In mesoscale analysis particular care must be taken to be sure that images are navigated accurately because as the time interval is made shorter, the error caused by a single pixel misalignment becomes larger (ex., ½ n mi displacement = 1 knot error with ½ hour interval, but 6 knot error at a 5 minute interval). It is a good practice to average several measurements to obtain each cloud motion vector.

An excellent review of current mesoscale cloud wind measuring techniques can be found in Chapter 3 of Suchman et al. 1981. Techniques for combining winds derived from measurements by radar, cloud motion, rawinsonde, and aircraft are reviewed in detail. Objective analysis of wind fields, especially mesoscale fields, is discussed, and schemes based on the Stanford Research Institute wind editing and analysis program, WIND*SRI (Mancuso and Endlich 1973) and one developed by Barnes (1973) are compared. A hybrid technique was developed for processing GATE data to produce plots of original vectors, smoothed vectors, gridpoint winds, streamlines and isotachs, u and v components, divergence, and vorticity alone or in any desired combination. Moisture information was incorporated with the windfield to predict cloud formation and precipitation (Negri and Vonder Haar 1980).

The fact that using cloud motions to get winds only works where there are clouds is not a serious fault in mesoscale analysis. Clouds are where the weather is and where the wind information is most needed. In BWOFS, for tactical operations, a cloud free area presents the easiest possible forecast. The greatest weakness in deriving winds from cloud motions lies in determining the height of the vector. Suchman et al. 1981, Chapter 2, is the latest and best available presentation of cloud height determination techniques. The advantages and problems of using IR image data for height determination and the best techniques to use are reviewed in detail. Work by Griffith, Woodley, Hansen, Twomey, Aida, Mosher, and others in determining cloud thickness is summarized and the limitations on using cloud brightness as a measure of thickness are explained. Currently, cloud thickness cannot be determined to better than a factor of two of the actual thickness by using brightness

measurements.

If temperature and humidity soundings are available in or near the cloud systems being analyzed, either from radiosondes or satellites, they can be used to determine the lifting condensation level from which the height of the cloud base can be inferred. Moisture profiles also help to determine heights and thickness of cloud layers, especially when several layers are present. The height of thin cirrus, which cannot be determined accurately from IR image data alone because of their "transparency", were determined during FGGE by using data from the TOVS (Kahwajy and Mosher 1981). The same technique is being employed using VAS multispectral data to produce highly accurate cloud top height maps rapidly over large areas with mesoscale resolution (Mosher 1982). Accuracy of cloud top height determination using the latest multispectral techniques is estimated to be better than ± 1 km except in special cases like those involving narrow cloud towers, and clouds too small to fill the sensor field of view.

Even with accurate cloud top height determination the proper height to assign the cloud motion vector remains a question. If a rawinsonde or aircraft wind profile is available, it can be used to help determine the "height of best fit" of a group of cloud motion vectors (Suchman et al. 1981, p. 51; also Suchman and Martin 1976). A special program to assist the analyst in determining height of best fit has been written for the McIDAS.

Measurement of cloud height from stereographic image pairs from two satellites has been tried (Hasler 1981, Suchman et al. 1981) and can produce highly accurate results. However, the practical problems involved in synchronizing the VISSRs on two operational GOES satellites have limited the collection of suitable image pairs, and the technique is not in regular use. Specialized satellites (such as TACSAT described under New Developments below) could be used to produce excellent stereo pairs for mesoscale analysis, and in some cases might even provide information about the height of cloud bases with good accuracy.

False stereo is a technique for generating an indication of pseudo-height by creating a second image by shifting clouds horizontally a distance proportional to their "height" determined from the simultaneous IR image (Hasler et al. 1981b). The original and the shifted image are shown simultaneously on a video display in contrasting colors and viewed through complimentary color filters which present one image at each eye of the viewer. The

resulting impression of a three dimensional scene can help greatly in sorting out relative cloud heights, especially when several images treated in this manner are shown in motion picture sequence. This technique can be used with polar orbit satellite images also, and has been used to contour humidity, instability, rain probability, and other parameters as well as "height" (Suchman et al. 1981, p. 32-33).

The Laboratoire de Météorologie Dynamique, Paris, has proposed a technique for measuring horizontal winds and for determining cloud heights by cross correlation of two pictures obtained from one satellite which is moving relative to the earth (Sitbon 1980). This concept, called the JANUS method, is an application of tomographic techniques frequently used to analyze aerial reconnaisance photographs. Although previous analyses of the idea have indicated probability of poor results, the technique is being tested by LMD, using an instrumented airplane.

It would be worthwhile to investigate the possiblity of modifying a DMSP OLS to provide two images of the same area taken from different points of view as an alternative to visual and IR images. In this case the PMP would be a real advantage because it would provide the highly stable platform required for accurate height and wind determination.

The accuracy of winds derived from cloud motion vectors has been assessed repeatedly by comparing vectors with rawinsondes (Bauer 1976, Suchman et al. 1975, Wilson and Houghton 1979), by comparing wind fields (Bizzarri and Sorani 1980, Maddox and Vonderhaar 1979), by chasing clouds with airplanes (Hasler et al. 1977), and by using cloud motion winds in computer models (Lee and Houghton 1981, Houghton et al. 1979, Tarbell et al. 1981). Findings indicate cloud motion vectors produce winds which compare with those produced by other measurements within 1.8 to 3.0 m sec^{-1} RMS. This is about the same correlation one finds between two sets of rawinsonde data (Bauer 1976). For synoptic scale wind sets, the evaluation of cloud motion vectors was summarized by M. Fea (1980):

> "Cloud motion vectors as representing the mean air flow advecting the cloud itself are still considered with suspicion by some meteorologists, the latter arguing how it could be wrong talking about 'wind' when tracking an object changing continuously in thickness, shape, and density like a cloud, and moreover when assigning a height to such a 'wind'. Nevertheless, and taking into account the completely different physics of measurements, it must be emphasized that the results

achieved during the Global Weather Experiment by the five geostationary satellites' system are good, despite the fact that the cloud tracking techniques are not standardized so far. The quality of the cloud motion vectors is almost comparable with the conventional winds, and the coverage by 'satellite winds' over oceans and sparse-data areas is very noticeable."

For mesoscale analysis Purdom (1981) stated:

"The geostationary satellite has the unique ability to frequently observe the atmosphere (sounders) and its cloud cover (visible and infrared) from the synoptic scale down to the cloud scale. This ability to provide frequent, uniformly calibrated data sets from a single sensor over a broad range of meteorological scales places the geostationary satellite at the very heart of both the understanding and nowcasting of mesoscale weather development. The clouds and cloud patterns observed in a satellite image or animated series of images represent the integrated effect of ongoing dynamic and thermodynamic processes in the atmosphere. When that information is combined with more conventional data such as radar, surface and upper air observations, then many of the important processes in mesoscale weather development and evolution may be better analysed and understood. It is from this better analysis and understanding of mesoscale processes that improved nowcasts will become possible. However, this basic and extremely important concept hinges on learning how to integrate satellite data and other meteorological data into uniformly cohesive data sets based on the uniformly calibrated, single sensor advantage provided by the geostationary satellite.

There are many yet to be answered questions about why the clouds or cloud patterns observed in satellite imagery appear as they do, or are evolving in a particular manner. However, that behavior and evolution is precisely the concern of a major portion of a nowcast. Understanding what the satellite image or image sequence is telling us is the key to developing accurate nowcasts. From the geostationary satellite we have an observation at least every half hour of the earth's cloud cover. These clouds and cloud patterns are the results of specific processes in the atmosphere. It is our task as meteorologists to understand these processes and extend them into the future.

Temperature, Pressure and Humidity

Remote sensing of temperature and humidity has been around long enough to have lost its novelty, but it has not yet been fully accepted and utilized operationally. At the risk of oversimplification, a brief review of the principles of remote sounding of the atmosphere may be helpful.

Physically, remote sounding by passive radiometers is possible because all matter not at the temperature of absolute zero radiates energy at one or more wavelengths characteristic of its atomic structure and amplitude proportional to its energy level. The trick is to select the wavelengths at which the matter of interest emits and to design sensors capable of measuring the amplitude

precisely. Sounding the atmosphere becomes a complex problem of peeking through many narrow keyholes, each of which provides a single number, and then processing these numbers to reproduce the vertical temperature and humidity structure.

Atmospheric gases not only emit energy, but absorb it as well, so the segments of the spectrum to be sensed must be selected so that part of the atmosphere of interest will be seen. For example, to measure temperature the wavelengths at which carbon dioxide emits but at which water vapor is inactive are used. Within these "water vapor window" regions several sensors are filtered to "see" only a very narrow band because the exact wavelength at which CO_2 molecules emit is a function of pressure as well as temperature; that is, most of the energy received in each band comes from a particular pressure level. Hence, by sensing several bands, information about the vertical temperature profile is collected. But sorting out the radiometer measurements to produce a temperature sounding is neither easy nor exact. The signal to the sensor is never "pure" because some energy is scattered in or out of the path, the exact percentage of CO_2 in the air may be different from that assumed, solid or gaseous pollutants add their confusion, etc. The mathematical problem is one of too many unknowns for the available information, so the answer has to be assumed before it is solved, then corrected and re-solved. The final answer necessarily contains both old assumptions and new information.

Nevertheless, the satellite soundings are used operationally as part of the global data base at the NMC and GWC and are being used increasingly for mesoscale analysis in research studies. Hillger and VonderHaar (1977, 1979) and Fritz (1976) used satellite soundings plus radiosonde data to produce details of vertical temperature structure function. Further work by Fritz (1981) and Molnar (1981) has extended and confirmed the concept in mesoscale analysis. By combining a few radiosonde profiles with many satellite soundings the objective is to realize the advantages of better vertical resolution of the radiosondes and the much greater horizontal resolution of the satellite data. Carefully done, the results may be good, but there is a danger that an error in a radiosonde run may be propagated unknowingly.

Since the signal from the lowest part of the atmosphere has the longest path to reach the satellite, it tends to be noisier and to produce greater errors. Several experiments have been conducted with radiometers on the ground nearly identical to those in the satellite (Little 1981, Hogg et al. 1979, Westwater

and Grody 1980) in which the ground-based soundings are combined with simultaneous satellite soundings over the same area. The ground-based data provide greater accuracy near the ground and serve to "anchor" the satellite sounding so that accuracy is improved at all altitudes. This technique appears to be particularly applicable to BWOFS since it does not require the balloons, gas, sondes, and related equipment of traditional radiosondes, and the ground-based remote soundings can be processed in a man-computer interactive system along with the satellite data.

The high horizontal density of TOVS data provides information at the mesoscale not available from the widely separated radiosonde stations. Mills and Hayden (1982) and Gauntlett (1981) demonstrated the value of these soundings in predictions using a mesoscale numerical model. Brodrick (1981) compared the prediction produced by the NMC computer analysis with and without TIROS-N sounding data and found that there was significant improvement with the satellite soundings. In fact, analysis using only the TOVS soundings was superior to that from NMC.

While satellites can produce soundings with high horizontal resolution, the vertical resolution is poor compared to that of radiosondes. Typical figures for vertical resolution are 2 to 4 km, and this limits the value of the soundings for some types of analysis. Or, it might be said that the poor vertical resolution has stimulated scientists to develop other methods of analysis to get around that limitation. Smith et al. (1982) described a method of using the GOES-VAS multispectral capability in a "Dwell Imaging" (DI) mode. In the DI mode the VAS scans the North American area in 8 of the 12 VAS channels over a half hour period to produce accurate quantitative maps of lower and upper tropospheric relative humidity, geopotential thickness, and atmospheric thermodynamic stability (total-totals index). The whole process can be repeated every half hour if desired (and the satellite is not used for some other purpose), and the resulting maps which are generated in real time can be displayed in motion picture mode on McIDAS to spot areas of atmospheric instability well before the development of storms.

The temporal resolution of VAS sounding data delineates atmospheric details at mesoscale which conventional radiosondes at 12 or 24 hour intervals or even polar orbit satellites at 3 to 6 hour intervals miss completely (Smith et al. 1982). Flexibility of VAS operation permits longer period dwell sounding of

areas of particular interest to produce very dense arrays of soundings where needed. Real time processing and display of results makes it possible for meteorologists to obtain a maximum number of soundings in a storm area while avoiding clouds.

Clouds, of course, are the biggest problem in sounding the atmosphere in the infrared part of the spectrum. There are three ways around the problem: One is to be sure to sound only where there are no clouds, another is to sound only down to the clouds (Smith 1971), and the third is to shift to a much longer wavelength to which clouds are nearly transparent. The microwave sounder in TOVS and the new SSH/T operate on the 5.5 mm O_2 emission band where the effect of water vapor and cloud droplets is minimal. In general, the accuracy and vertical resolution of microwave soundings is about the same as for IR soundings, but the horizontal resolution is much poorer. Since the wavelength of the radiation is a thousand times longer, the receiving sensor aperture would have to be equivalently larger to achieve the same field of view. The IR sensors in TOVS have a 1.2° view angle versus 7.5° for the Microwave Sounding Unit. The advantage of being able to see through clouds is gained at the cost of horizontal resolution which is needed for mesoscale analysis. Using data from both IR and microwave sounders in an interactive system provides the best data set (Smith et al. 1979c) obtainable from current polar orbit satellites.

Satellites measure the total integrated moisture content of the atmosphere very well (Gruber and Watkins 1979), but the resolution of the vertical distribution of moisture is poor compared to radiosondes. It is inherently more difficult to sound for moisture than for temperature. For temperature, sounding measurement frequencies are chosen so that absorption will be relatively constant and the signal at the satellite is a function of only atmospheric temperature. For moisture, frequencies must be chosen so that the signal is a function of both atmospheric temperature and the concentration of absorbent water vapor. The moisture determination is highly dependent on the temperature structure. Also the sounder is severely limited in seeing through a wet layer to determine what lies below. Thus total moisture can be sensed well, but it is difficult to pin down its distribution. However, the distribution of moisture is of great importance in mesoscale forecasting (Kreitzberg 1976).

Once again the greater horizontal resolution of the satellite soundings provides advantages which compensate in large measure for the lack of vertical

resolution. Hayden et al. (1981) describes a method of analyzing VAS data to provide moisture information of considerable value for numerical forecasting and for subjective short-term forecasting alike. His method makes three major changes in current operational procedures:

(1) The surface contribution to the radiance measurements is subtracted before processing the data. This increases the sensitivity of the measurements to lower level moisture gradients.

(2) The temperature/moisture solution is iterated to force satisfaction of the radiative transfer equation for low-level moisture.

(3) In cloudy areas a cloud moisture model is used to extend the sounding below the cloud.

The result is a map of low and middle tropospheric moisture in rather thick layers (surface - 700 mb and 850-500 mb) but with very good horizontal gradient pattern definition. The GOES-VAS capability can produce this kind of map every half hour to provide a very powerful mesoscale analysis tool.

At present, atmospheric pressure cannot be measured from satellites. A technique for making surface pressure measurements was described by Smith and Plat (1977), but it has not been implemented and probably will not be. Mesoscale analysis techniques have moved away from use of pressure fields and toward greater use of temperature, moisture and wind fields superimposed on satellite images in interactive video displays. The requirement for pressure measurements to support aircraft operations has also become less important with the increased use of radio altimeters and electronic guidance systems for landing.

Satellite-borne passive radiometers provide temperature and moisture information at high horizontal resolution, and the newer geosynchronous satellites provide excellent data with high temporal resolution as well. The science of remote sounding from satellites is still very young, and the value of such measurement is increasing as improved data processing methods produce better products and as meteorologists develop the capability to apply the products. With the advent of the VAS generation of geosynchronous satellites, the tremendous potential for describing the thermodynamics of mesoscale events in real time is beginning to be realized. Further growth and improvement is assured, and BWOFS must be designed to take maximum advantage of this new technology.

Precipitation

Rain falls nearly everywhere sometime, but on highly irregular schedules and with very non-uniform distribution. It is extremely difficult to determine

how much rain has fallen with a high degree of accuracy. Rain gauges and radars are the two "conventional" data sources, and they both have well known shortcomings. It is understandable, since information about rainfall is in great demand, that people would try remote sensing from satellites. Much effort has gone into developing schemes to use visible and IR images to deduce rainfall amounts and even to develop special sensors to detect and measure rainfall from satellites.

Fortunately, the capabilities for deducing precipitation from satellite data have been thoroughly reviewed and fully reported in Barrett and Martin (1981). They conclude (p. 311) that in the mesoscale, and probably at larger scale over land also, the "life-history" methods of rainfall monitoring are most successful. The life-history methods are based on the premises that significant precipitation comes mostly from convective clouds, and that convective clouds can be identified in satellite images. Three somewhat different analysis techniques are described, those of Stout, Martin and Sikdar (1979), Griffith and Woodley (Griffith et al. 1976, Woodley et al. 1980), and Schofield and Oliver (1977, 1980). These schemes utilize the brightness of the cloud in the visible image, its top temperature from the IR image, the growth rate of the cloud, and evidence of convective intensity such as overshooting tops and cloud merging. Thus, all of the techniques depend on the use of sequences of images from geosynchronous satellites. Further, because there must be several pictures of the cloud during its lifetime, the techniques work best if the interval between images is less than the usual 30 minutes. All three schemes presuppose the use of a man-interactive display to enhance and sequence images and to measure areas.

Good results in rain-rate determination were obtained by Wiley (1979) by combining cloud image data and radiosonde data in a one dimensional convective cloud model (Simpson and Wiggert 1969). The method was tested using GOES data over the Montreal, Quebec area, and results were compared with radar rain-rate measurements obtained by the McGill University 10 cm weather radar. Results were encouraging, and this technique deserves further study and testing on a larger scale.

Results of the life-history methods have been generally good, and the Schofield/Oliver technique is used at the National Severe Storms Forecast Center to determine rainfall amounts. A second set of McIDAS equipment is being installed at the World Weather Building expressly for rainfall monitoring and

the generation of flash flood warnings using the Schofield/Oliver method.

Barrett and Martin raise questions about the reliability of passive radiometers in measuring rainfall over land. These questions will be resolved when the DMSP SSM/I has been in operation long enough to collect significant amounts of data. There appears to be no doubt that good rainfall maps can be generated by SSM/I over water. However, the field of view of the SSM/I is larger than most convective rain cells and this will cause errors. Also, the lifetime of rain cells, and even of large convective assemblies, is short compared to the sampling interval provided by two DMSP satellites. The SSM/I rainfall data will be of use to the GWC by providing large scale rain patterns and climatological statistics, but may offer little help to BWOFS because of poor time and space resolution. Soil moisture, the after effect of precipitation, has been measured by visual, IR, and microwave passive sensors (Idso et al. 1975). Visual-albedo is a nearly linear function of water content of the soil surface during the first of the three classical stages of the soil drying process: (1) evaporation proceeds at a rate dictated by atmospheric conditions; (2) evaporation rate decreases rapidly as it is limited by "hydraulic conductivity", a characteristic of the soil type; (3) evaporation rate levels out at a very low rate approaching zero as hydraulic conductivity is lost. During the second and third stages visual sensors provide no useful soil moisture information.

Infrared sensors detect soil surface temperature and wet soils are cooler during the day but warmer at night. The thermal inertia of the water provides an accurate indication of moisture if the soil surface is bare and if soil type, surface wind, and relative humidity are known. When the parameter, "tension between soil and moisture," is used as a measure, it is independent of soil type. Soil maximum-minimum diurnal temperature measurements work, and so does the maximum difference between soil and air temperatures. This technique fails if there is cloud or vegetation cover, or if surface wind is not known.

Microwave sensors detect soil moisture because the dielectric constant for water is high at microwave frequencies and it is low for dry soils. Therefore, surface emissivity varies with soil moisture. For example, at 21 cm wavelength, "brightness temperature" (temperature x emissivity) decreases 2.2 K per 1 percent increase in soil moisture above a minimum value dependent on soil type. The soil surface temperatures must be known to obtain good results from microwave sensors.

Visual and IR sensors work at the surface only, while microwave sensors average to a greater depth (up to 10 cm) and are relatively independent of soil type. Visual detection does not work well in sandy or porous soils. Microwave sensors are relatively free of cloud interference, but are sensitive to soil salinity which can be high in some areas. Crop cover is a problem for all the sensors.

A more sophisticated method of determining soil moisture depends upon monitoring the rate of evapotranspiration from fields covered with crops or grass (Soer 1980). An IR line scanner was used to sense crop surface temperatures which, with the aid of the energy budget equation, aerodynamic heat and water vapor transport equations, and soil-plant-water relationships, yielded actual evapotranspiration rates. Provided crop type and atmospheric conditions are known, a series of determinations of evapotranspiration rate can yield accurate information about soil moisture to considerable depth. This method works best when soils are unsaturated, while the three methods above are most accurate with wet soils.

A simpler method was used to relate values from NASA's Heat Capacity Mapping Mission to determine soil moisture and soil temperature (Heilman and Moore 1980). A significant exponential relationship was found between the volumetric soil water content in the top 4 cm of soil and the diurnal soil surface temperature measurement (0230 and 1330 local, the satellite overpass times). Soil surface temperatures were estimated from minimum air temperature, percent vegetation canopy cover, and satellite measurements of canopy temperature. Results were good for a number of different crops and soils.

The DMSP-SSH/I system is supposed to map soil moisture with 50 km horizontal resolution from dry to saturated at 1 percent quantization levels. Quite realistically, no absolute or relative accuracy is promised. A review of available documents (Hollinger et al. 1978, SAMSO TR-76-119 1976) which present the theoretical studies and test results upon which the SSH/I design is based do not provide much reason for confidence in the ability of the instrument to measure soil moisture operationally. On the other hand, no other method with a higher probability of success has been proposed. Soil moisture measurement by remote sensors is still highly experimental and it is too early to draw conclusions about the value of the SSH/I data. For BWOFS it is most important to know when the soil is near or at saturation because it is at this end of the wetness scale

that trafficability is most affected. It is highly probable that SSH/I data will delineate very wet soil areas, and that such qualitative mapping will meet the most important BWOFS requirements.

NEW DEVELOPMENTS

Of the many ideas for new or improved sensors, satellites, or data systems, two could make very significant contributions to BWOFS and are discussed further below. One is a concept for a new synchronous orbit satellite system dedicated to collecting the data required for mesoscale analysis and prediction. The second is for the ultimate passive radiometer sounder which could provide vertical resolution sufficient to meet most mesoscale analysis needs. Both of these new developments can be achieved with present technology. If both were brought into operation mesoscale analysis and prediction could become an effective and routine service for both civilian and military interests.

Other new developments worth noting, but not recommended for BWOFS, are:

1. Satellite-Borne Lidar Global Wind Monitoring System (Huffacker 1978, Huffaker et al. 1980, LMSC 1981). A series of feasibility studies have been completed under the joint sponsorship of the NOAA Environmental Research Laboratories and the Air Force DMSP System Program Office. The concept is to fly a pulsed CO_2 laser ranging system in a low orbit satellite to illuminate aerosol particles in the atmosphere and to detect Doppler-shift in reflected energy. Performance objectives are to measure winds as follows:

   a. Horizontal resolution of 300 to 400 km at surface
   b. Vertical resolution of 1 km from surface to 15 km
   c. Wind speed to $\pm$ 1 ms^{-1}, direction $\pm$ 10^o

   If entirely successful as studied, the system would map wind fields where there were no clouds and where sufficient density of aerosols provides an adequate signal return. Questions of effects of turbulence and vertical motion remain. The system could provide data of considerable value to large scale numerical analysis at GWC, but would be of little value to BWOFS.

2. Numerical prediction models are being developed by several agencies. The recent report on Mesoscale research (NRC 1981) by the Committee on Atmospheric Science, NRC, listed the following models, and still did not include them all:

SUMMARY OF CLOUD-SCALE MODELS ACTIVE IN 1980

Model Identification[a]	Domain	Emphasis	Contact	Remarks
One-Dimensional Steady-State Models				
BUREC	20 km (vertical)	Cloud top, vertical motion, seeding potential	Matthews	
SDSMT	20 km (vertical)	Cloud top, vertical motion, seeding potential, plume transport	Hirsch, Orville	Used for maximum hailstone size prediction
NOAA/ERL	20 km (vertical)	Cloud top, vertical motion, seeding potential	Woodley	Used to predict co-variates in weather modification project
CSU/1D	20 km (vertical)	Cloud top, vertical motion, seeding potential	Cotton	
One-Dimensional Time-Dependent Models				
SDSMT	20 km (vertical)	Cloud microphysics, hail prediction	Farley, Orville	
Two-Dimensional Models				
U. Ill./2D	48 km x 14 km	Single clouds, severe storms	Soong, Wilhelmson	Axisymmetric and slab symmetric models
U. Wisc./2D	~50 km x 15 km	Severe storms	Schlesinger	Liquid bulk water microphysics, slab symmetry
CSU/2D	35 km x 17 km	Tropical Cu, mountain Cu	Cotton	Slab symmetry
NCAR	18 km x 12 km	Detailed cloud microphysics, ice and liquid processes	Hall	Slab symmetry
SDSMT/2D	20 km x 20 km	Hailstorms, cloud electrification, cloud modification	Orville, Farley, Helsdon	Some detailed ice microphysics, slab symmetry
Hawaii/2D	6 km x 6 km	Detailed microphysics, hailstone growth, cloud electrification	Takahashi	Axial symmetry
RAND	10 km x 10 km	Tropical Cb, ice bulk water microphysics	Murray, Koenig	Axial symmetry
U. Wash./2D		Detailed microphysics, particularly ice phase	Hobbs	Axial symmetry
Three-Dimensional Models				
U. Wisc./3D	48 km x 48 km x 14 km	Severe storms	Schlesinger	Liquid bulk water microphysics
CSU/3D	35 km x 35 km x 17 km	Tropical Cb. mountain Cb	Cotton	Some ice bulk water microphysics
NCAR/Ill./3D	48 km x 48 km x 16 km	Severe storms	Klemp, Wilhelmson	Liquid bulk water microphysics
NCAR	50 km x 50 km x 15 km	Hailstorms	Clark	Liquid bulk water microphysics
NCAR	10 km x 10 km x 17 km	Tornado genesis	Rotunno, Klemp	Nested in 3-D cloud model
Hawaii/3D	6 km x 6 km x 4km	Tropical Cu, detailed liquid microphysics	Takahashi	
NOAA/GFDL	3 km x 3 km x 2.5 km	Tropical Cu	Lipps	Liquid bulk water microphysics

[a]See Appendix B for key to abbreviations.

SUMMARY OF REGIONAL-SCALE MODELS ACTIVE IN 1980

Model Identification[a]	Spatial Dimensions[b]	Typical Horizontal Grid Size; Domain Size	Typical Vertical Grid Size	Emphasis	Contact
GFDL	2, 3	50 km 2500 km × 2500 km	1 km	Tropical cyclones Fronts Meso-α predictions with real data	Kurihara, Orlanski, Ross, Miyakoda
Drexel	2, 3	40 km 2000 km × 2000 km	1 km	Precipitation, meso-α, β predictions with real data	Kreitzberg, Perkey
U. Va.	2, 3	10 km 400 km × 400 km	1 km	Sea breezes, mountain-valley breezes	Pielke
Penn State	2, 3	20–100 km 800 km × 800 km to 4000 km × 4000 km	1 km	Precipitation, meso-α, β predictions with real data, sea breezes, fronts	Anthes, Warner, Seaman
ERL/OWRM	3	20 km 800 km × 800 km	1 km	Mesoscale convective complexes	Fritsch
	3	5 km 200 km × 200 km	500 m	Terrain effects Orographic precipitation	Nickerson
NHRL	2, 3	20 km 3000 km × 3000 km	1 km	Tropical cyclones	Rosenthal, Jones, Willoughby
NMC	3	60 km 3000 km × 3000 km	1 km	Tropical cyclones Mesoscale precipitation	Hovermale Phillips
SUNYA	3	18.5 km 389 km × 426 km	300 m Top 2.5 km	Coastal front	Ballantine
Navy	3	60 km 3000 km × 3000 km	1 km	Tropical cyclones	Madala, Hodur

[a]See Appendix B for key to abbreviations.
[b]The two-dimensional models predict the variation of the variables in one horizontal dimension and in the vertical. The variation in the other horizontal direction is either neglected or specified.

Perhaps the most promising near-mesoscale model, and the one most likely to see operational service soon, is one developed at the Australian Numerical Meteorological Research Center (McGregor _et al_. 1978, Gauntlett 1981) and currently being used in a modified form by the NESS/SSEC Cooperative Institute for Meteorological Satellite Studies (Mills and Hayden 1982). While this model is really a sub-synoptic scale rather than a mesoscale model (70 km data grid), it has demonstrated the capability to resolve circulation elements of about 150 km wavelength (estimated). The ability of such a model to generate fine scale vertical detail starting with a relatively smooth initial state has been demonstrated (Anthes _et al_. 1981, Mills and Hayden 1982), provided it is initialized with data of high horizontal resolution. That is, the high horizontal density of the TOVS data provides the information required by the model to generate the vertical structure which was not apparent in the TOVS soundings. This might be a useful device to determine cloud base heights for BWOFS, but much further testing is needed.

Eventually, one or several numerical prediction models will be used operationally to predict mesoscale weather. However, no such capability exists at this time. The prudent course is to proceed with BWOFS now to meet the urgent needs of the Air Force, but to anticipate increasing use of models as they are proven. In any case, we can be certain that geosynchronous orbit satellite data will be a major data source, and that man-machine interactive data processing systems will be required for whatever models are used.

The TACSAT and HIS systems described in the next two sections are the necessary steps toward BWOFS. It is recommended that the Air Force, in coordination with NOAA and NASA, take the steps necessary to implement them as rapidly as possible.

TACSAT - A New Satellite Concept

In the 1970-74 period NASA studied the requirements for, and feasibility of a new satellite system called the Synchronous Earth Observatory Satellite (SEOS). The satellite was to be a rather large telescope (1.8 m aperture) mounted in a three axis stabilized spacecraft placed in geosynchronous orbit. A great many applications were projected, including:

Forest fire patrol	Ice packs in Great Lakes
Crop disease watch	Iceberg patrol
Tornado watch	Location of forest perimeter
Coastal shipping watch	Sea temperature monitor
Coastal fog watch	Weather pattern observation

A large number of sensors were proposed, including several imaging systems, a complex on-board data processing system, and everything else required to make it a long-lived operational satellite.

SEOS died of over-complexity and unresolvable design conflicts posed by the large number of missions. However, the studies which were performed by several agencies while investigating the SEOS concept developed some interesting and potentially important ideas. The study of meteorological uses of SEOS was performed at the University of Wisconsin by the staff of the Space Science and Engineering Center and by a group of graduate students in the Department of Meteorology, all under the direction of Professor Verner E. Suomi (Suomi et al. 1973). The large number of persons involved and their broad range of skills and attitudes made this an unusually productive study.

At the outset it was recognized by all the participants that SEOS might be a data source of great importance to mesoscale meteorology. The study became an effort to determine what needed to be measured for the analysis and prediction of a number of mesoscale events, and to what extent SEOS could be expected to produce these measurements. As a sensor platform SEOS offered a great deal:

1. A relatively small inertial mass stabilized and pointed by control moment gyros and momentum wheels would permit fairly rapid movement of the telescope.
2. A high gain, 1.8 m aperture, reflective optic telescope would provide high resolution and sensitivity even at fairly long wavelengths.
3. A 2.5 megabit-per-second data link would provide more than enough communication capacity for frequent measurements.

The first step was to select a set of mesoscale situations to study and to identify what observables one needs to measure to analyze and forecast each. This was the job for the meteorology graduate students. The next step was to determine how to make the necessary measurements and whether they could be made from SEOS. This was the job for the SSEC staff of physicists, meteorologists, and design engineers.

The phenomena studied by the "Mesoscale Monitoring Seminar," as the graduate students called themselves, were:

Severe storms and tornadoes
Hurricanes
Lake and sea breezes
Air pollution
Frost
Flash floods
Clear air turbulence

The list tends toward spectacular events, but if you are trying to sell a new satellite program these are the flags you wave. Actually, the observables required to analyze a situation leading to a forecast of thunderstorms are the same as for any convective event, and together the list includes consideration of nearly every weather situation BWOFS will have to contend with except some causes of lower atmospheric turbidity such as fog, blowing snow, and dust storms.

Each of the phenomena was analyzed meteorologically, and a list of knowledge requirements was assembled, discussed and defended. For example, for flash floods, the list was:

Extent and state of surface water
Snow and ice cover and depth
Monitor output of numerical models (synoptic analyses)
Precipitable water
Vertical stability, 1000-800 mb
Vertical stability, 800-100 mb
Atmospheric motion field 1000-800 mb
Atmospheric motion field 800-100 mb
Precipitation extent, type, and intensity
Monitor surface condition and history
Moisture inflow
Locate and track local storms and squall lines
Locate regions of strong convective activity

Consolidation of the seven lists of knowledge requirements and translation into meteorological terminology yielded the following key parameters in order of importance:

1. Boundary layer motion field
2. Vertical stability
3. Temperature lapse rate and surface temperature
4. Regions of strong convective activity
5. Middle and upper troposphere motion
6. Surface pressure field
7. Moisture field
8. Convergence and divergence
9. Wind shear, jet stream location

The lengthy discussions which follow in the SEOS report explain how many of the nine key parameters could be inferred qualitatively by detailed analysis of images with high spatial and temporal resolution. In most cases fairly accurate quantitative estimates could be made entirely from image data, and good short-term subjective forecasts were possible. However, it was emphasized that the addition of surface, radiosonde, and radar observations made the forecasting job

easier and probably better. Temperature and humidity soundings from SEOS were specified with maximum emphasis on vertical resolution at lower levels.

Following the demise of the SEOS program, the concept of a pointable imaging system capable of delivering high resolution images of small areas on demand as frequently as desired continued to be discussed and studied by the staff at SSEC. In 1976 a study report entitled, "The MESOSAT System: A Tool for Quantitative Observation of Mesoscale Weather" was finished. The report updated the SEOS study results and proposed a much smaller, less expensive satellite design dedicated solely to mesoscale weather data collection. The principal characteristics of MESOSAT were:

1. A three-axis stabilized, SMS sized spacecraft using radiation cooled solid-state sensors.
2. Visible images at 300 m resolution covering an area of about 180x150 km (a standard TV frame). IR images at lower resolution.
3. Images requested by local forecaster delivered to him by direct transmission from satellite within minutes of request.
4. Images repeated at intervals as short as two minutes.

The report includes results of a fairly detailed design study of the imaging optics. The objective was to design a telescope with a 7° acceptance angle (covering an area about 6000 km in diameter on the earth's surface) within which the mesoscale image could be selected electronically or by moving minimum mass. It was considered to be impractical to move the whole spacecraft or even the telescope to point to each image area; instead, the main telescope would "see" a continent-sized area continuously, and the desired image would be selected from the large field. The proposed solution was for a Gregorian optic with movable section containing secondary and tertiary reflectors and sensors. A sketch of this design is shown in Figure 1. Technical improvements in solid state, electronically scanned sensors would allow a somewhat smaller and lighter design, but the MESOSAT concept was entirely feasible in 1976. MESOSAT system performance specifications were:

A. Visible Imaging:

Ground resolution	300 m
Spectral band	0.4 - 1.1 μm
Dynamic range	$>10^7$ (for nighttime imagery)

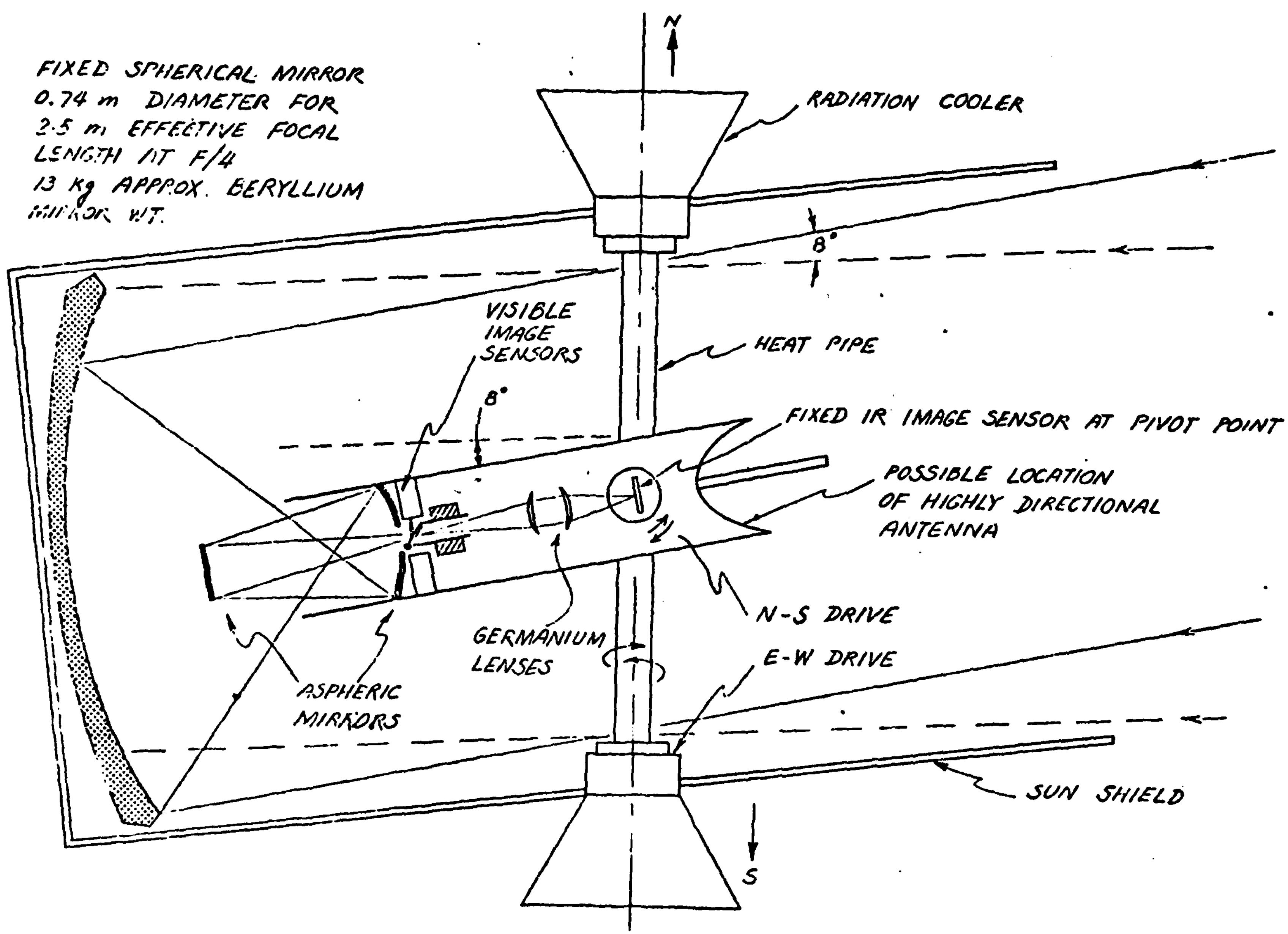

FIG. 1 GREGORIAN WITH MOVABLE SECONDARY-TERTIARY AXIS, F/4, 6.3% OBSCURATION, 8° ACCESSIBLE FIELD DIA.

Signal to noise ratio	>150:1 @ 100% albedo
Gray scale digitizing	128 levels (linear)
Raster geometry	Uniform, picture to picture determinable to <½ pixel
Raster shape	Frame 525 x 632 pixels (TV format compatible)
Area coverage (varies with scale of pheonmenon)	10^4 - 10^6 km^2 (one or more frames as needed)
Picture intervals (per target)	2 min to 2 hours (4-5 sec/target)
Frame time	5 seconds
Information bandwidth (constant)	∿ 500 Kbps
Data type	digital
Pointing knowledge	20 μr (post facto)
Permissible drift	<½ pixel per exposure time

B. IR Imaging:

Ground resolution	5 km
Spectral Bands	6.7 μm ($\Delta\nu$ = 150 cm^{-1}) 11.5 μm ($\Delta\nu$ = 160 cm^{-1})
$NE_{\Delta}T$	0.5° C @ 225° K
NER	0.1 $mW/(m^2cm^{-1}$ ster,) 0.05 $mW/(m^2cm^{-1}$ ster.) at 6.7 μm
Raster geometry	uniform picture to picture or determinable to ½ pixel
Raster shape	frame
Area coverage (varies with scale of phenomenon)	10^4-10^6 km^2 (one or more frames as needed)
Picture interval (per target)	2 min - 4 hours (4-5 sec/target)
Frame time	-5 seconds
Information bandwidth	-5 Kbps
Data type	digital
Pointing knowledge	20-30 μr

The MESOSAT spacecraft was to be as simple and long-lived as possible. All sensors would have redundant backups. There would be no tape recorders or similar high performance mechanical devices. The command vocabulary would be very limited. All image requests were to be sent via land line to a control center where they would be stacked and sent to the satellite at the time the image was desired. Thus, no command storage was required on the satellite.

Attitude would be corrected once each day to keep the area of interest in view, and the spacecraft would be allowed to drift for 24 hours with only nominal momentum wheel stabilization. Actual image location ("navigation") would be checked periodically against landmarks and correctors would be applied at the control center to pointing commands to keep images within a pixel of requested location.

Data would be transmitted via a continuous 500 kilobit per second data link. At about 6 GHz a 1.5 m dia parabolic antenna reflector would have a 3 dB beam width of about 7° just covering the area of interest. A 30 watt transmitter would provide plenty of signal, even in bad weather, into a 2 m dia ground antenna.

Only a few modifications are required to convert MESOSAT into the ideal satellite system for BWOFS. The imager should be designed to include a 3.8 μm channel for high resolution imaging day and night. Perhaps it should replace the 0.4 - 1.1 μm visual channel. The command up-link would have to be protected to prevent jamming, and data encryptors would have to be added to the down link. And the name should be changed to TACSAT.

It is strongly recommended that a full scale design study of the TACSAT system be undertaken as part of the PRESSURS development program.

<u>The High Resolution Interferometer Sounder (HIS)</u>

(The following was excerpted nearly verbatim from a proposal for the HIS Phase II study submitted to NASA by the NESS/University of Wisconsin Cooperative Institute for Meteorological Satellite Studies dated May 1981:)

OVERVIEW

The High Resolution Interferometer Sounder (HIS) program began in 1978 with a joint University of Wisconsin/NOAA proposal to NASA. Based on the contemporary work of Kyle (1977), Alyea and Goldstein (1978), and Smith et al. (1979a), a three-phase program was proposed, aimed at the implementation of a geostationary earth orbit (GEO) sounding instrument capable of achieving one degree centigrade temperature accuracy, 10% moisture accuracy, and the highest vertical resolution achievable by passive radiometric techniques. The design study phase (I) of the original proposal, funded jointly by NASA and NOAA, has been completed. A hardware design concept was developed by the Santa Barbara Research Center (SBRC 1981) and BOMEM, Inc. which can satisfy all the HIS GEO instrumental requirements with state-of-the-art and proven hardware. At the same time, extensive theoretical studies and numerical simulations conducted by NOAA and the University of Wisconsin scientists have affirmed the theoretical soundness of the HIS approach for overcoming the vertical resolution limitations of contemporary satellite sounding devices (e.g., HIRS and VAS). HIS would provide profile data with the high accuracy required for weather analysis and forecasting on the global, regional, and meso-scales of atmospheric motion.

Finally, studies during Phase I show that an aircraft instrument capable of demonstrating the HIS concept can be assembled at low cost from standard BOMEM system components. The aircraft instrument would be capable of collecting data for synthesizing observations from current sounders (e.g., VAS and HIRS) and other infrared sounders proposed for future development (e.g., the HIS and AMTS). This would allow direct comparison of the performance of existing and proposed sounding approaches from actual atmospheric observations.

JUSTIFICATION

Satellite soundings contribute greatly to improved global numerical weather prediction (Bengtsson 1979). For mesoscale applications, soundings from TIROS-N are now being used on an experimental basis for the delineation of atmospheric conditions responsible for severe weather (Smith et al. 1979b). The new VAS geostationary satellite sounding capability initiated with the launch of GOES-D has demonstrated the ability to observe, for the first time, the diurnal evolution of atmospheric weather processes (Smith et al. 1981).

Furthermore, soundings from geostationary platforms are superior to those from low orbiters for global scale forecasting as well as for regional and mesoscale prediction. This is because geostationary altitude observations can be made on a nearly synoptic time scale (i.e., the data are collected over a vast area in a short time interval).

Although satellite soundings are playing an important role in today's weather analysis and forecast operation, improvements in their vertical resolution are needed, particularly for the proper delineation of baroclinic zones. In order to achieve a significantly higher vertical resolution than presently possible, a drastic improvement in spectral resolution (i.e., a factor of 40) must be achieved without sacrificing either signal to noise or spatial resolution. An "optimally scanned" interferometer sounder has been designed which will make this possible. Optimal scanning minimizes the time spent measuring the interferogram regions containing little information about the thermal emission to space, while maximizing the time spent measuring the regions where information about the fine scale spectral structure of the emission spectrum is concentrated. The result is a set of radiometric observations which resolve fine spectral (and therefore vertical) detail with high signal to noise. Simulation results show that fine scale vertical temperature structure can be retrieved from the intended HIS measurements with an accuracy close to one degree centigrade throughout the troposphere and lower stratosphere (i.e., surface to 30 mb). Greatly improved moisture profile accuracy can also be achieved.

EXPECTED PERFORMANCE

The results of simulations show that the HIS approach offers the opporunity to realize a dramatic improvement in sounding capability. Figure 2 compares the rms temperature errors for the HIS global, regional, and mesoscale modes to a case representing the capability of the VISSR Atmospheric Sounder (VAS).

Near the tropopause and near the surface where sounding is most difficult, an improvement in excess of 1.0 C is indicated. Practical dwell times for the three HIS modes shown (based on the GEO conceptual design) are 0.6 sec for the global mode, 1.7 sec for the regional mode, and 7.5 sec for the mesoscale mode. The dwell time for VAS is about 1.5 sec. The VAS case assumes an interferogram noise equivalent radiance of 15 mW/m^2 sr (with 395 interferogram samples per cm), which, for a maximum delay of 0.05 cm (20 cm^{-1} apodized spectral resolution), is equivalent to a spectral radiance noise of 0.25 mW/m^2 sr cm^{-1}. This is the noise level which VAS can obtain in its 15 μm channels for the nominal operating mode in which multiple scans are averaged to yield an effective footprint of 30x30 km. For this comparison we have used only the 15 μm band. Simulations performed using the HIS 4 μm band radiances with an unapodized spectral resolution of 2 cm^{-1} and a noise equivalent radiance of 0.0033 mW/m^2 sr cm^{-1} show improved retrievals from 850 mb to the surface (for the 4 μm retrievals, the regression solution used brightness temperatures, not interferogram radiances). At the surface, the rms temperature error is reduced from those shown in the figure to 0.2 degrees centigrade. In addition to improving retrievals in the lower troposphere, the 4 μm band radiances will also be important for surface temperature retrievals and for minimizing the influence of clouds.

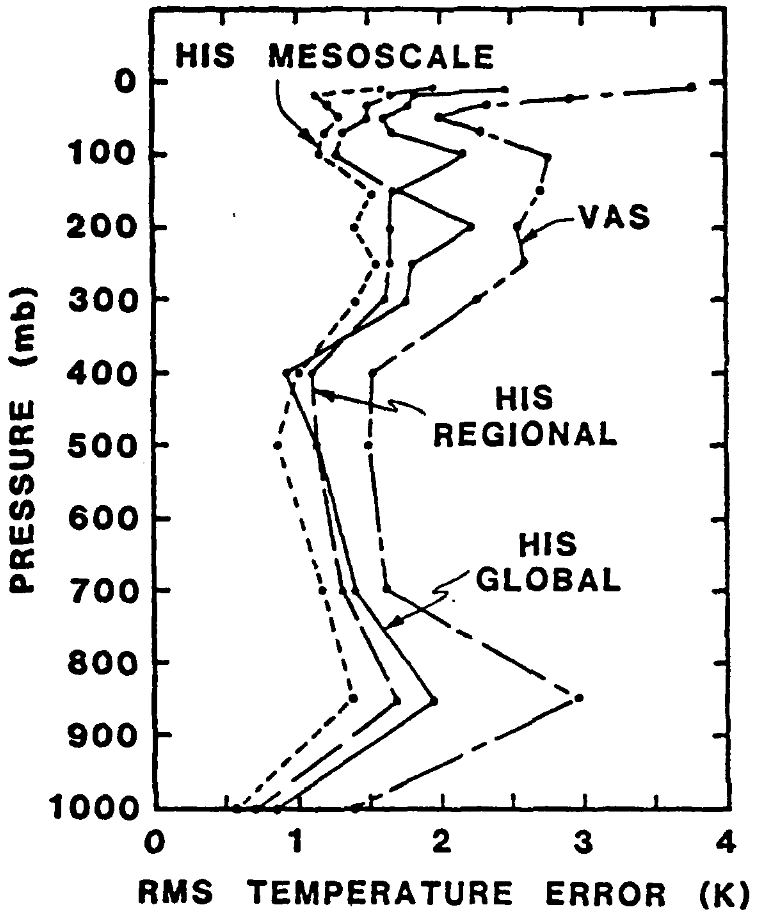

Figure 2. Simulated HIS global, regional, and mesoscale mode rms temperature errors compared to a case representing VISSR Atmospheric Sounder (VAS) performance. The value of the HIS regional and mesoscale modes is especially noticeable near the surface and near the tropopause.

SUMMARY

To support U.S. tactical battlefield operations accurate and timely weather forecasts are required at three levels of military command. Typically, the forecast period (hence, the scale of weather systems involved) is different at each level. At the top, the theatre commander must plan 24 hours or more ahead over large areas. At the mid-level, mission planning requires forecasts 12 to 24 hours in the future in specific areas of probable operations. At the lowest organizational level, mission execution requires weather information as accurate and as specific as possible from current to 12 hours ahead, updated at

three-hour or shorter intervals over specified target areas about 50 km in extent.

At the top level the global scale operations of the GWC provide as good weather service as can be found anywhere. The DMSP and TIROS satellite system provide a major source of data to GWC over the entire globe, and the only source over large polar and oceanic regions. At present, the polar orbit satellite data is critical to the GWC global data base.

The mid-level requirements are at the lower end of the synoptic scale, still well within the range of GWC's prediction models and data base. At this scale all four polar orbit satellites are needed to satisfy data requirements and geosynchronous satellite information is very useful. Current numerical prediction models provide good forecasts and better models are on the way.

At the wing level, a mesoscale analysis and forecasting service is required. Here is where the major problems exist because:

1. The AWS and NWS have allowed their mesoscale analysis and prediction capabilities to deteriorate under budget pressures and preoccupation with building effective centralized facilities for synoptic and global scale prediction.
2. The polar orbit satellite systems provide image and sounding data at more than adequate spatial scale; however, the time interval between data sets is far too great to meet mesoscale needs.
3. Geosynchronous orbit satellites currently provide good data for mesoscale analysis and forecasting, but the U.S. satellites cover only North and South America and large ocean areas. The Far East and Europe/Africa are covered by satellites controlled by other countries, and the mid-Asia/India area is not covered at all. The U.S. GOES are not under military control.
4. The concepts and equipment for man-computer interactive data processing systems which are essential for effective use of existing and future satellite data have not yet been made available to the AWS. The necessary technology exists and is in use by others, but the Air Force has not moved to procure it.

The current generation of geosynchronous meteorological satellites can provide the basic data required for BWOFS. The Air Force should move to obtain control of a minimum number of GOES-VAS type satellites and necessary ground equipment to insure an adequate data source over the short run.

Even more important and of greater urgency than providing adequate data sources is the need for the AWS to upgrade its forecasters in the use of modern man-machine interactive systems in mesoscale analysis and subjective

prediction techniques. BWOFS is not possible until trained personnel and adequate data processing facilities are in hand.

In the long run, the Air Force should develop and operate geosynchronous satellites designed specifically for tactical battlefield weather support along the lines of TACSAT and with interferometric sounder capability.

A ROAD MAP

We recommend the following route to BWOFS:

Phase I.

Select several (at least 3 or 4) AWS Base Weather Stations in the U.S. which must satisfy short-term forecast needs similar to those of BWOFS. Furnish these stations with full-sized modern man-computer data processing capabilities (like McIDAS or CSIS). Do not try to specify a "military" system nor buy less than the best. Buy what is available and get systems that have the greatest flexibility even though they are obviously not designed to be "operational" and appear to be oversized. Provide each of these stations with the antennas and receiving equipment which will allow them to receive GOES stretched data from two satellites, including VAS AA mode data. Also give them the equipment needed to readout DMSP and TIROS-N satellites. Make sure the computer with its man-interactive system is big enough to process sounding data as well as do all the other things that a good interactive system does.

As soon as the lucky Base Weather Stations have been picked, start training people -- both observers and forecasters -- to understand and know how to use the interactive equipment. Expect to spend lots of time on training -- there is a whole new technology to transfer. When the hardware and software are in place, let the trained people play with it, get used to it, and eventually use it to produce forecasts. Do not establish a BWOFS SPO or Development Office or any other big program superstructure. Just keep it a small project in AWS with some AFGL help and lots of free exchange with universities, NESS, and others with experience in interactive systems and satellite data processing. Give the people at the Base Weather Stations as much freedom as possible. After a year's shakedown, let them start to modify the software to do things their way. After a second year, let them specify larger scale changes to both software and hardware and, if possible, give them what they want. After the third year, or maybe the fourth, this part of the program is ready for Phase II.

Meanwhile, have AFGL and the SAMSO SPO get busy on engineering studies and meteorological impact studies for TACSAT. Start out with the full intention of building TACSAT on a priority schedule. It can always be stopped later if it does not work out. At the DoD/DoC level, work out an arrangement which will push NOAA and NASA to proceed with the development of HIS. Also negotiate with NOAA for purchase of two or three GOES-VAS satellites which would be modified with encription and up-link protection for interim use by the Air Force if the need arises. If TACSAT comes along before the AF GOES-VAS satellites have to be used, sell them back to NOAA. Include in the deal with NOAA either purchase or loan of the necessary ground equipment (SDBs, etc.) to operate the satellites if needed.

Of course, AFGL should continue with development of the ground or airborne equipment to augment the satellite data which the PRESSURS studies conclude is required.

Time for Phase I is four to five years; cost is about $4 million.

Phase II.

The first thing to do in the second phase is to assess what has been accomplished in the first phase. Do it carefully and in detail. Reassess the requirements for BWOFS too because as the capabilities change, so will the use of them. Be sure the people who have been working with interactive systems have a strong voice in the reassessment. They will have some new perceptions and different understandings of what the BWOFS job is.

If the reassessment clearly shows that Phase I was on track and that the equipment and techniques required to put an effective BWOFS in the field can be specified with a high degree of confidence, go ahead and write the specifications. If, as is more likely, the reassessment shows that the road to BWOFS is still not clearly defined, then shift the effort to the areas that need it, and spend another year or two learning what has to be learned. It is far better to extend the program while it is small and before so many people become involved that change becomes impractical. Keep the development and learning work out in the Base Weather Stations and use operating personnel instead of R&D types. Give the laboratories and the SPO relatively well defined, limited tasks with firm deadlines so that their more involved procedures will not delay the main effort.

The objective of Phase II is to produce the documentation which the procurement people need to buy the parts of BWOFS. Set down firm guidelines at the beginning that will forbid the preparation of a "systems" specification. Instead, specify BWOFS piece-by-piece and then procure it that way too. Keep the interfaces between pieces simple and flexible so that some pieces can be changed without affecting others. Do not buy any piece until all doubts concerning its design have been removed by thorough investigation and testing. Buy only a few of each piece at first, and use them before buying more. Expect to make a few changes as the process of procuring continues. Take some time and do not let the procurement process force purchase of poor equipment.

Since the AWS and NWS both need much better capabilities for short-term forecasting in their normal service, much of what will be bought for BWOFS will also be needed in every weather station. Plan on it, and when the opportunity arises, buy enough pieces to build up the Base Weather Stations generally. BWOFS will function better the more it resembles regular peacetime weather service.

At the end of Phase II the AWS should have a good BWOFS capability. Enough people should have been trained and enough equipment purchased to handle any Viet Nam-sized operation. Time required for Phase II is five to six years. Cost could run from $20 million to $200 million or more, depending on how the satellite developments and procurements progress.

Phase III.

This phase is simply a reiteration of Phase II. Start with a thorough assessment of capabilities and adjust development and procurement activities accordingly. At about this point so many people will have become involved that Phase III will resemble "normal" AWS/AFGL/SAMSO management activities.

ADDENDUM "A"

WEATHER, DATA, AND PREDICTION IN BWOFS

THE SCALES OF WEATHER

That part of the atmosphere that contains the weather, the part between the surface and the troposphere about ten miles above, has the shape of a thin sheet with horizontal dimensions approximately 2500 times greater than its thickness. The proportions of the weather layer are nearly the same as those of the sheet of paper this is printed on. This thin film, which is not heated uniformly by the sun, breaks up into continents and islands of warm and cold air which impact each other as they circulate. The large scale weather systems, the fronts, highs, and lows, result from the interactions of these thin plates of air. The dimensions of the atmosphere restrict large scale weather systems to two dimensional circulation patterns. A vertical structure exists of course, but on the large scale, vertical motion is small compared to the horizontal wind fields. Meteorologists usually model large scale weather as a series of horizontal planes with the vertical structure a secondary consideration.

Predicting the movement and modification of the large air masses is relatively easy. National weather services maintain networks of observing stations which produce measurements several times each day that clearly delineate the air masses as cold or warm, moist or dry, locate their boundaries, and describe their motions. The Air Weather Service can predict the position of a front, the boundary between air masses, with considerable precision for periods several days into the future. But as we all know, predictions of the weather are frequently inaccurate. The reason, of course, is that the weather, the summation of the things that the atmosphere is or does that affects people, results from a very complex intermixture of phenomena ranging in scale from large air masses of continental size down to the infinitesimal.

The matter of scale is important to understanding the problems of observing and forecasting weather phenomena for tactical air operations. Everyone knows

something about the differences between local and large scale weather systems, but a great deal of new information has been developed during the past 15 years. Meteorological observations from satellites have played a major role in producing greater understanding of the spectrum of meteorological phenomena and their interactions.

Atmospheric structure and behavior are generally categorized as macroscale (or synoptic) at the large end of the spectrum, microscale at the small end, and everything in the middle is called mesoscale. The terms "synoptic"* and "micrometeorology" have been in use for at least a century, but "mesometeorological" was first proposed 30 years ago (Ligda 1951) to describe precipitation formations which, "occur on a scale too gross to be observed from a single station, yet too small to appear even on sectional synoptic charts." Ligda proposed the name to make it easier to discuss the new phenomena which he and a few others were revealing through the use of radar.

It is difficult to realize that only thirty years ago knowledge about the atmosphere was practically limited to synoptic scale air mass phenomena that could be described by a network of observing stations spaced over 100 miles apart, or micrometeorology which could be measured by soil thermometers and laboratory instruments. Knowledge about atmospheric structure was limited to fair weather because that was what rawinsondes could measure or what could be seen from the ground or from airplanes. Radar brought the first opportunity to observe the structure and dynamics of the inside of storms and meteorologists were able to begin to fill in the large mesoscale gap in the spectrum of atmospheric phenomena (Barrett 1979).

The term "mesoscale" is still too new to have a commonly accepted definition. Fujita (1981a) proposed an array of subdivisions within the general "mesoscale" as shown in Figure 3. Figures 4 and 5, also from Fujita (1981b), illustrate the application of his nomenclature to typical high and low pressure systems. Fujita's samples are worth studying because they illustrate the complex interrelationship of phenomena of different scales and different

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* The dictionary meaning of "synoptic" is "observed at the same time" and was applied by meteorologists to measurements made by observers at designated times to provide a "snapshot" of the atmosphere. Because observing stations were established at intervals of about 120 miles the term "synoptic" has by usage been extended in meaning to characterize the scale of weather event which the observing networks were capable of resolving.

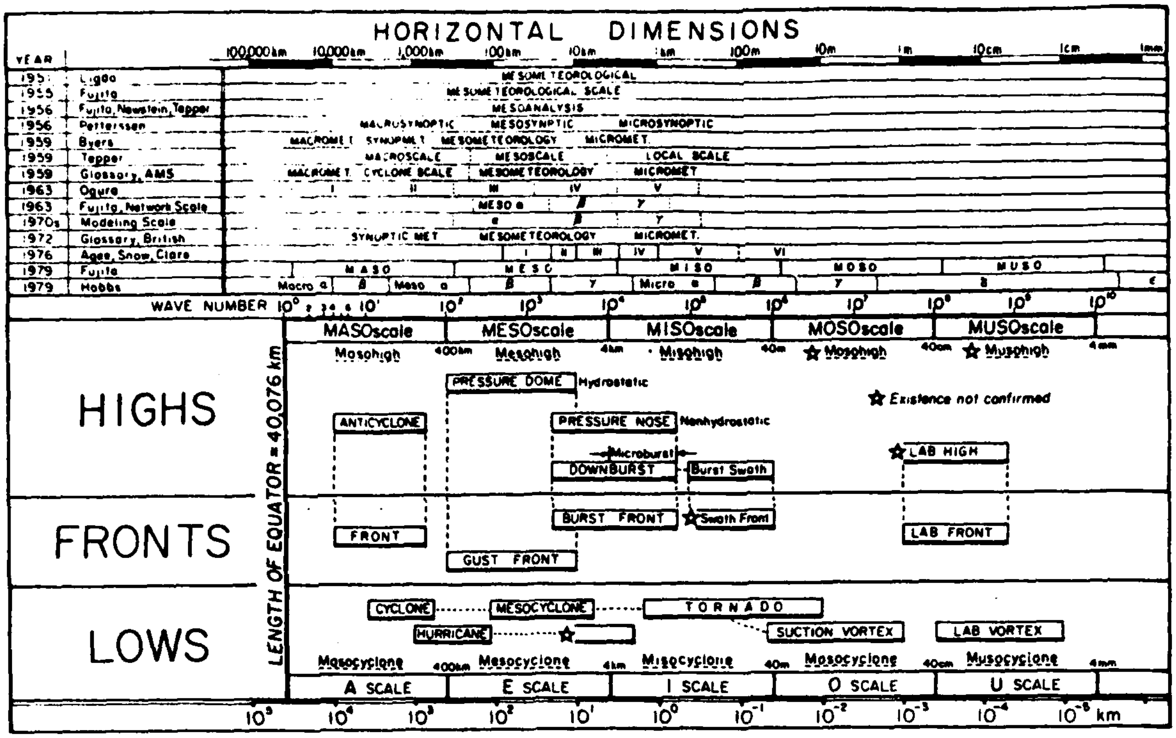

FIG. 3. A diagram showing the historical definitions of the mesoscale along with the fine scales, maso-, meso-, miso-, moso-, and musoscale proposed by Fujita. (From Fujita, 1981b.)

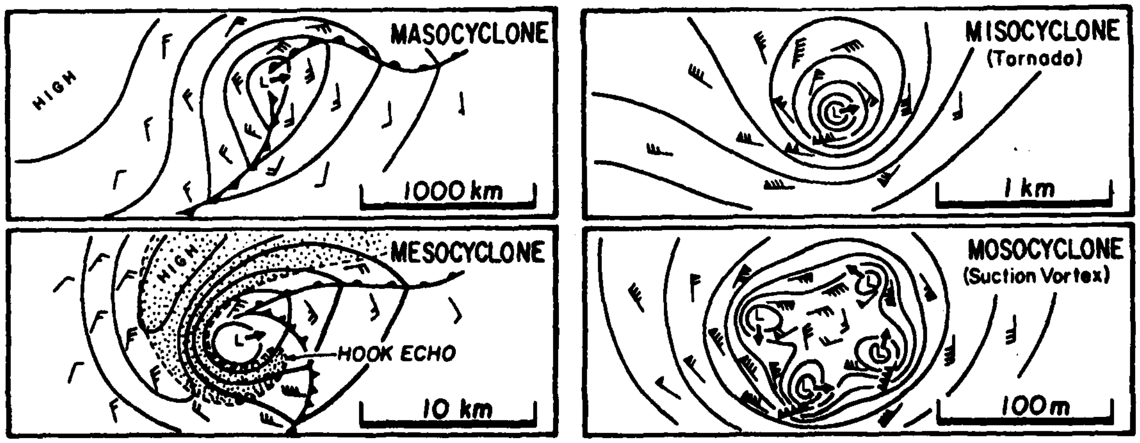

FIG. 4. Schematic drawings showing the features of maso-, meso-, miso-, and mosocyclones. (From Fujita, 1981b.)

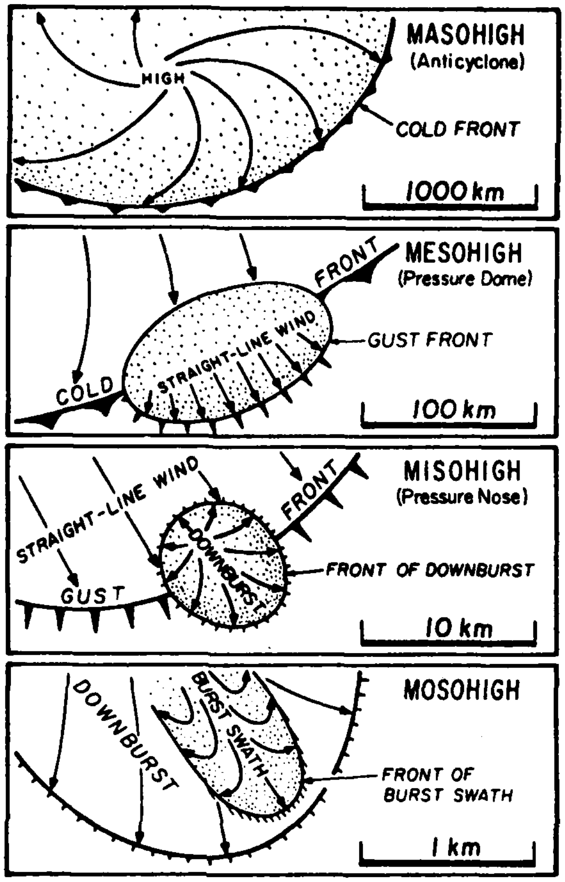

FIG. 5. Schematic drawing showing the airflow patterns accompanied by maso-, meso-, and mosohigh (unconfirmed). (From Fujita, 1981b.)

dynamic structures, all of which are combined in a single "storm".

Pielke (1981) has proposed a definition of "mesoscale" as, "those atmospheric circulations which have horizontal scales large enough to be essentially in hydrostatic balance, yet small enough so that the wind field deviates substantially from gradient wind balance above the planetary boundary layer." Pielke also suggests, "the mesoscale can be defined more qualitatively as having a temporal and horizontal spatial scale smaller than the conventional rawinsonde network, but significantly larger than the size of individual cumulus clouds. This implies that the horizontal scale is on the order of a few kilometers to one hundred kilometers or so, with a time scale of about one to twelve hours. The vertical scale extends from tens of meters to the depth of the troposphere."

A consensus on a definition of "mesoscale" may not be reached for some time. One scientist (Zipzer 1981) says, "One of the problems in mesoscale meteorology today is that the phenomena are still being discovered and described, and that such a large range of scales is included that 'mesoscale' means different things to different people." Zipzer goes on to point out another factor which has served to mislead many meteorologists who are not engaged in research but who have to meet operational forecast requirements. Far more attention has been spent by the research scientists on the less frequent, but more spectacular, severe storm or tornado situation than on everyday mesoscale occurrences. In Zipzer's words, "In the U.S. many anecdotes can be related about researchers focusing radars on severe convective cells at the leading edge of a squall line, ignoring massive strataform precipitation, even driving home through it, and later questioning its existence." As a result the research community has been slower than it might have been in developing the methodologies needed to improve the bread-and-butter daily forecasts. Also, the preoccupation with severe weather has caused the term "mesoscale" to become nearly synonymous with severe storms in the minds of many, but the severe storms are only the exceptional cases. Mesoscale processes are omnipresent, just as are macro, and microscale processes. It helps to remember that the spectrum of meteorological occurrences is continuous and constant.

"Mesoscale systems can be categorized into those which are primarily forced by the ground surface (i.e., terrain-induced mesoscale systems) and those which are substantially driven by synoptic scale features (i.e., synoptically forced mesoscale systems)" (Pielke 1981). It is probably not an overstatement to say that all mesoscale events are either terrain or synoptically induced or are triggered by some combination of these two factors. Examples of terrain-induced phenomena include land- and sea-breezes, urban circulations, and forced airflow over mountains. Synoptically forced events include squall lines, hurricanes, ensembles of convective cells (Mesoscale Convective Complexes - Maddox 1980) and tropical cloud clusters (Martin and Sikdar 1975).

At the synoptic scale, a forecaster can predict the movement of large scale features which, in combination with the terrain over which they move, alter the probability of occurrence of a weather event. For example, let us assume that on 29 December the GWC macroscale model predicts the passage of a cold front through southern Wisconsin during the afternoon of 30 December.

The forecaster predicts lower temperatures and increasing cloudiness with confidence, and suggests a 30 percent probability of snow with possible accumulation up to three inches. He cannot be more certain about whether it will snow because if snow occurs it will come from clouds formed by mesoscale circulations which do not yet exist but which will be triggered by the front and perhaps intensified by a lake or an urban warm area, or a row of hills in just the right spot. If snow does occur it will be limited in extent and will not cover the whole forecast area. This is the kind of forecast which would be furnished for planning purposes at theatre command headquarters if (heaven forbid!) a tactical air strike were expected to be required in the area west of Madison, Wisconsin on the evening of 30 December.

At theatre command the strike is laid on because the enemy's tanks will be there, but the weather situation is going to make the selection of which PGM's to use very difficult. A much more detailed forecast will be required in 12 hours covering specific sections of major highways and other likely routes for the invader's forces. To select the right PGM's for the strike, the wing level planners have to know if the ground will have snow cover and about how much, if the ground will be frozen and to what depth, what the air temperature will be and whether it is rising or falling, what the cloud cover will be and how high the cloud base is, what the seeing conditions will be -- whether it will be snowing or not and at what rate, whether there will be blowing snow or haze, and what the humidity profile is between the ground and the cloud base. They need the proability that the forecast is correct to be high and they need the forecast to be specific to each possible target area. Incidentally, a target area is defined as being about 50 km (31 miles) in extent, and the battle front may include a large number of target areas. As time for takeoff approaches, they need to have the information updated and corrected until the probabilities approach certainty.

The tactical weather requirement is for an effective <u>mesoscale</u> analysis and prediction capability. The technical knowledge required to provide this capability exists now but not in the operational Air Weather Service. The problem to be solved is how to alter and augment the existing system to provide effective tactical battlefield weather support.

WEATHER PREDICTABILITY

In papers by Thompson (1957), Robinson (1967), Lorenz (1969a) and Roberts (1971) the ultimate limits of predictability of the atmosphere were investigated theoretically. While their studies differed in approach and reasoning, their conclusions are in general agreement that at any particular scale there is a finite limit to the time that atmospheric conditions can be predicted. Thompson used an approach in which the properties of the atmosphere were averaged statistically over all space and time intervals and the total kinetic energy of the motion field ensemble was compared in two different conditions. The difference he treated as a measure of the error between actual and predicted states. By examining the first and second derivatives of the average ensemble energy error he concluded that small errors in the observations from the existing ground station network would double in about two days.

His analysis obtained a useful figure for rate of error growth, but only at the scale determined by the spacing of the observing stations. Thompson concluded that the error growth rate could be reduced considerably by increasing the number of observing stations.

Robinson observed that in any fluid system a circulation element eventually loses its identity as a result of interaction with smaller scale elements. He reasoned that the equations of fluid flow dynamics could not produce predictions at a particular scale for a longer time than the elements at that scale retained their identities. Following this reasoning, he determined predictability of atmospheric phenomena ranging from several days for synoptic scale events to about an hour for cumulus cloud sized circulations.

The subject of predictability was treated more generally and in greater depth by Lorenz in his exceptionally well written paper. Lorenz set out to examine the basic question of whether the atmosphere should be considered to be a deterministic system, and concluded that even if it were, the observable behavior is indistinguishable from that of an indeterministic system. Lorenz was careful not to extend his theoretical findings to the real atmosphere without appropriate cautions and caveats; nevertheless, his work provides highly useful guidance in developing a mesoscale prediction capability.

Lorenz developed a model using the vorticity equation which described "error kinetic energy" at all scales from the lower limit of dissipation by molecular processes to the upper limit determined by the earth's dimensions.

He invested his model with a total kinetic energy equal to that estimated for the earth's atmosphere with a scale spectrum distribution according to the "minus-five-thirds Law," and then watched the growth of errors of several magnitudes introduced at small, medium, and large scales. Error was permitted to grow at each scale until it approached the magnitude of total energy at that scale; i.e., until all "predictability" had been lost.

Initial errors grew at rates proportional to their own magnitude and inversely proportional to their scales. Both of these are expectable results since a larger error should lead to more rapid divergence between the "real" and "simulated" cases, and the entire lifetimes of small scale circulations are short compared to the larger scales. Errors in smaller scales affected the next larger few scales in which error grew to affect the next larger scales, etc., until it reached the largest scale where it grew at a rate appropriate to that scale. Conversely, there was an immediate strong effect of large scale errors on all smaller scales. Again, one could anticipate these results. For example, misspecifying the distribution of cumulus-sized clouds would have little effect on the location of a front, whereas a small error in placing the front could completely displace the cumulus clouds in space or time.

The most important conclusion which Lorenz's study indicates is that for any particular scale of atmospheric motion there is an intrinsic limit of predictability. Values of the predictability limits versus scale size as found in one of Lorenz's numerical experiments are given in Table 6 and shown graphically in Figure 6. Extension of Lorenz quantitative results from his theoretical models to the real atmosphere involves risk, but subsequent studies (Roberts 1971) indicate that this extension is justified and that the limits of predictability which Lorenz computed are probably close to those of the real atmosphere.

k	$2N_k^{-1}$	Y_k	t_k
21	38 m	.0001	2.9 min
20	76	.0002	3.1
19	153	.0003	4.0
18	305	.0004	5.7
17	610	.0007	8.4
16	1,221	.0011	13.0
15	2,441	.0017	20.3
14	4,883	.0027	32.1
13	9,766	.0043	51.1
12	19,531	.0067	1.3 hr
11	39 km	.0104	2.2
10	78	.0160	3.6
9	156	.0246	5.8
8	312	.0373	9.5
7	625	.0558	15.7
6	1,250	.0817	1.1 day
5	2,500	.1160	1.8
4	5,000	.1566	3.2
3	10,000	.1935	5.6
2	20,000	.1970	10.1
1	40,000	.0925	16.8

Table 6. Range of predictability, t_k, for scale k as determined by Experiment A. Also given are maximum wave length, $2N_k^{-1}$ included in scale k and energy, Y_k (dimensionless units), in scale k for Experiment A. (From Lorenz 1969a.)

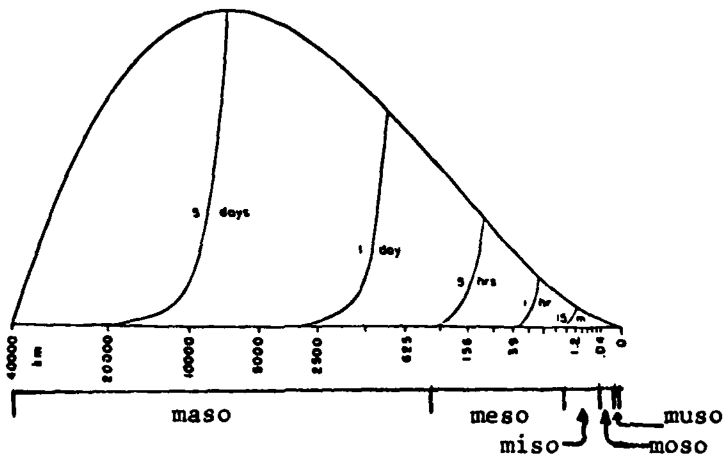

FIG. 6. Basic energy spectrum (heavy curve), and error energy spectrum (thin curve) at 15 minutes, 1 hour, 5 hours, 1 day, and 5 days, as interpolated from numerical solution in Experiment A. Thin curves coincide with heavy curve to the right of their intersections with heavy curve. Horizontal coordinate is fourth root of wave length, labeled according to wave length. Resolution intervals are separated by vertical marks at base of diagram. Vertical coordinate is energy per unit logarithm of wave length, divided by fourth root of wave length. Areas are proportional to energy. (From Lorenz 1969a. Fujita's scale division added for reference.)

Current numerical prediction models operate with an internal data grid spacing compatible with the mean spacing of the network of observing stations. The grid-point spacing determines the smallest scale which the model can resolve. Information about any smaller scale constitutes noise or observational error which degrades the performance of the model. Conventional surface and rawinsonde measurements are made by sensors which respond rapidly to their immediate surroundings; hence, these measurements contain information about much smaller scales than the forecast models can recognize. Elaborate procedures have been developed to filter out the smallest scale information from the observations (Cressman 1959, Eddy 1967, Kruger 1969, Rutherford 1972) before the data are in-put to the models to minimize unwanted computational disturbance. In fact, synoptic scale models run most smoothly when the observational data are restricted to scales appreciably larger than their internal grid point spacing is capable of resolving. As a consequence it may be that data are over-filtered in practice and that the scale of motion actually being forecast is larger than the modeller intended. Earlier studies (Smagorinsky 1963, Mintz 1964) which indicated that the time required for errors to double in numerical models was twice that predicted by Lorenz may have obtained that result because of

over-filtering.

In general, in-situ meteorological observations are not suited to the business of weather forecasting. The urge to make measurements more "accurate" has tended to increase resolution and precision; that is, to generate instruments with short response times which sense a small volume of the atmosphere. What is really needed are sensors which integrate in space and time to provide observations representative of the smallest scale which the prediction model can resolve, but which average all smaller scale information (Barrett 1979). This capability is inherent in remote sensors and constitutes one of the great advantages of data provided by meteorological satellites. It is also unfortunately true that in situ measurements tend to be spaced relatively far apart; hence are able to define only large scale weather phenomena. Satellite sensors, on the other hand, provide data points much more closely spaced which allows analysis of mesoscale events.

Lorenz's work shows that errors introduced at the smallest scale grow rapidly in that scale and gradually influence larger scales until reaching the largest scale in the system. At the largest scale the error increases at the rate characteristic of that scale until the limit of predictability is reached. How then, should one design a data collection and prediction system to obtain the best possible forecast?

Given a particular model, there will be a lower limit of resolution determined by the internal grid-point spacing. If the data which feed this model are collected by a network spaced to match the scale of the model's grid points and are analyzed and smoothed to remove all smaller scale information, then the ultimate predictability of the model will be less than the possible maximum by an amount equal to the characteristic predictability of the scale just smaller than the resolution of the model. That is to say, if one truncates the spectrum of scales, the predictability of the larger scales remaining is reduced by the same amount as the intrinsic predictability of the largest deleted scale. As Lorenz (1969b) states it:

> "Specifically, if the largest scale of motion not resolved by the observational network has an intrinsic range of predictability of, say, three days, introducing a fine enough network to resolve all scales of motion (an impossible task, or course) would increase the realizable range of predictability of all the larger scales by just three days. likewise, improving the network so that the largest remaining unresolved scale has an intrinsic range of one day, instead of three days, would increase the realizable range of predictability of the larger scales by two days."

As shown in Table 6, the network spacing would have to be reduced by a factor of about four (an increase of data approaching a factor of 64) to realize the increase of predictability in Lorenz's example. In the end, the costs associated with data volume will determine how close a system can approach the theoretical limits of predictability.

Some general guidelines for the design of an effective yet practical tactical weather prediction system can be deduced from the above:

1. The smallest scale of motion which is to be predicted must be chosen deliberately, and carefully, because this factor determines the size and the cost of the data collection and prediction systems.

2. The observing system should be designed to produce data at spatial and temporal intervals adequate to resolve scales of motion significantly smaller than the scale to be predicted. How much smaller is a trade-off between system performance and cost, but a reasonable objective would be about one-half scale.

3. Optimum instrumentation would integrate over time and space to eliminate all information about scales smaller than that desired. Collecting, transmitting, and processing data at scales smaller than are needed is an inefficient and costly practice.

4. The prediction system, whether a numerical model in a computer, or a subjective forecast by a person, or some combination, should be designed to handle the scales of motion from the smallest determined by the resolution of the observing system to the largest global circulations. Truncating to eliminate scales too small to be of interest is permissible, but all larger scales must be retained.

MESOSCALE PREDICTION

Operational mesoscale forecasting currently is limited to special requirements, demonstrations, and an increasing number of private companies. That is, there is no regular service to the general public. On the other hand, research programs aimed at the development of better mesoscale prediction capabilities are plentiful and productive. In the opinion of many persons who have been active in the development programs, the technology necessary to produce accurate mesoscale forecasts operationally is in hand (Pielke 1981; Rosier, *et al.* 1981; Hauser 1981; NCR 1981) and mesocale forecast services could be implemented rapidly. However, there are problems of many types to be solved before the AWS can provide effective tactical battlefield mesoscale forecasting service.

Probably the first major effort to provide accurate short-term, small-scale predictions on a regular operational basis was in response to the needs of

military and civil aviation for terminal forecasts. The great increase in the number of aircraft and the growth of air transportation after World War II placed urgent demands on meteorologists to improve forecasts of weather during take-off and landing operations. The need was met by the combination of new observing instruments (ceilometers, transmissometers, improved anemometers) located at the ends of runways, and development of local area forecast aids and analysis techniques. At the same time, the development of electronic landing aids and better runway lighting made safe aircraft operations possible during previously prohibitive weather conditions.

In the 1950's terminal forecasts were made by subjective future projection of the weather situation. Most forecasters prepared sectional charts of the terminal area in which all available data were plotted and analyzed. Most weather stations had catalogs of prior weather situations and climatological data which provided information peculiar to that location to guide the forecaster (Cushman 1960). Because the terminal forecast was important, and it was prepared frequently, the local forecasters developed considerable skill in analyzing mesoscale circulation patterns (to the extent that available data permitted) and in predicting on the basis of his understanding of the meteorological event.

During the last thirty years several factors have altered, and to some extent have eroded the mesoscale forecasting capabilities of the Air Weather Service.

1. Improved landing aids have diminished the impact of weather on routine aircraft operations at established airfields. The Terminal Area Forecast (TAF) is less critical.

2. Weather radars now provide pilots and weather observers enough information to help pilots avoid the worst weather.

3. The development of numerical prediction capabilities at the GWC encouraged centralization of forecast services which reduced dependence on the local forecaster.

4. Budget constraints forced reductions which reinforced the tendency to "let GWC do it."

In a 1969 AWS manual (Falzgraph 1969) stated:

> "One of the most significant duties in our base weather stations is the preparation of the local terminal forecast (TAF). In fact, it is probably the only really creative effort still left to our detachments. Most of the other types of forecasts issues ... are extracted

primarily from one or another of the various centralized products received ..."

But the movement to centralized services continued, and another AWS report (Diercks 1970) issued the next year said:

> "Over the past decade ... improvement in day-to-day terminal weather forecasting has not kept pace with improvement in numerical prediction of upper air features."

Diercks goes on to detail a four phase program to improve the TAF by increasing the quantity of GWC produced forecast products, establishing a new TAF verification program, optimizing climatological aids, and development of other aids.

Not everyone saw the move to greater centralization as an improvement. Snellman (1971), in a paper which pointed out how closely the TAF was becoming linked to central computer products, said:

> " ... It is also important at this time that we emphasize the role of the forecaster because many forecasters are interpreting the considerable work being done in automation as efforts to eliminate their jobs rather than to help them do a better job. Unfortunately, this erroneous interpretation is affecting forecaster morale, and such work should really be improving morale."

Whether or not Snellman made this statement with tongue-in-cheek, the record shows that top level administrators did indeed substitute central computer resources for local forecasters when budget cuts forced moves to economize.

In 1973 primary responsibility for all forecasts 6 hours or longer into the future was placed with GWC and local forecasters were prohibited from altering the GWC forecasts without prior approval for each specific case from GWC (Dickover 1982). Also, the BWS forecasters were encouraged to use the GWC products as the basis for their forecasts of up to 6 hours. This period marked the furthest swing toward centralization by the AWS.

Research and development programs have been oriented toward automation and centralization. The Air Weather Service urged development of fully automated prediction systems for terminal forecasts (Tahnk 1975, Chisholm 1978, Geisler 1979, 1981, AWS GR 3-76). R&D programs conducted by or for the NWS followed a similar pattern: emphasis on centralization of forecasting functions,

and development of highly automated systems to measure and make short term extrapolations of terminal area weather conditions.

The shift to centralization and automation resulted in loss of capability on the part of local forecasters to do dynamical analysis. Also, the AWS has been losing the older forecasters who retained skills learned when dynamic analysis was still popular (Carron 1982). As these old-timers retired, their replacements moved into an operational environment where the local forecast was either pulled from the GWC (or NMC) product or produced by a semi-automated statistical extrapolation process. They were seldom required to produce a mesoscale forecast "from scratch" by careful analysis of the dynamics of the local weather situation.

Hills and Beer (1981), in viewing the meteorological scene over the past three decades, observed that the attitudes of meteorologists and their agencies appeared to fall into one of two easily recognizable groupings, namely:

> "1). That meteorology is an exact physical science that aims at explaining features of the atmosphere. This leads to research and development policies that stress sound theory and assume that public services will be improved by way of understanding atmospheric processes better. This results in tactics whereby problems are solved by breaking them down into smaller and smaller components until a level of simplicity is reached such that each part can be solved by acceptable scientific methods. This is known as the reductionist approach.
>
> "2). That meteorology is a public service and that this is more important than its scientific method. The accuracy of forecasts, for example, becomes more important than the method of achieving them. The end is more important than the means, while the reverse is true of the reductionist position."

While the author of this report is not a proponent of the "there-are-two-schools" approach to problem solving, still Hills and Beer make some good points. It is true that for the past 30 years the reductionist philosophy has dominated meteorological R&D and the operational weather services as well. Among other effects, this has encouraged "scientific" forecasting by numerical models in large computers at the expense of "practical" forecasting by subjective means more closely tied to users' actual needs. Wide acceptance of the reductionist attitude has shifted the decisions concerning how weather information is to be generated from those whose job it is to generate it to a relatively small group of senior meteorologists/scientists/administrators whose

decisions are strongly influenced by factors having nothing to do with the generation of weather information or its use. The reductionist approach has led to a system development and procurement procedure which: (1) requires weather data users to state requirements in great detail whereas they may actually be poorly understood and impossible to specify precisely, (2) places all development responsibility in the hands of scientists and engineers totally removed physically and philosophically from the real need, (3) encourages the "systems" procurement concept whereby a large company is expected to produce everything necessary to meet requirements in a huge one-time effort, and (4) forces the previously ignored field forecaster to accept whatever the "systems" contractor produces and to make the best of it.

One need only contemplate the carcasses of dead weather "systems" which litter the R&D landscape of the past three decades (433L, AFOS, SDHS are a few) to realize the fatal inadequacy of the "systems" development and procurement approach when applied to a meteorological service setting. On the other hand, one can recall examples of successful innovation in the weather business (such as the GWC's Nephanalysis) which have been produced entirely by the operational personnel without the involvement of the R&D agencies, the systems procurement process or outside contractors.

All, or very nearly all, of the hardware, software and techniques required to produce an effective tactical battlefield weather support system already exist -- but not in the hands of the AWS forecasters. The challenge lies in changing long held attitudes and realizing that the solution lies in retraining field forecasters to make effective subjective predictions, and in providing them with the tools which already exist. The emphasis must be on the field operations, not on the development laboratory. The approach must be evolutionary rather than by a large "system" procurement.

Fortunately, there is evidence that the reductionist attitude is losing ground and that a better balance is being established. In 1976 the AWS 5th Weather Wing started a "Back-to-Basics" educational program to strengthen their forecasters' analytic skills which had deteriorated through under-utilization (7WW Tech Note 78/003, 1978). This program was picked up by Hq AWS and incorporated in an expanded Follow-on training program in May 1978. The program continues at this time, although it appears to have become "routine".

In November 1978, the AWS Policy Board decided to return primary responsibility for all forecasts up to 24 hours in duration to field units. The GWC

retained responsibility for those beyond 24 hours (AWS Reg 105-27 change dated 1 Mar 79). Since that time GWC has discontinued products intended to support TAF's.

In March 1981, the AWS announced that all Base Weather Stations would be provided some sort of meteorological satellite image data to support TAF. This policy is now explicated in Annex G, "Policy White Paper - Weather Data from Satellites," to the AWS Capabilities Master Plan (CMP) 1982-1996 dated February 1982.

The more recent actions by Hq AWS to update and strengthen AWS mesoscale forecasting capabilities are most encouraging. However, there is still a strong dependence on automated or other "objective" prediction schemes at the base weather station which are based on statistical probability compilation. To some extent there is no practical alternative because the data and the data processing facilities required to do rapid dynamic analyses are not available at base weather stations. To establish why it is important to recover the competence of local forecasters to practice mesoscale dynamic analysis and prediction rather than to depend upon statistical schemes, let us look at the two forecasting methods in greater detail.

STATISTICAL PREDICTION

(Much of the first part of the following discussion was taken almost verbatim from Roberts (1971). The arguments have been extended beyond those contained in Roberts' paper and responsibility for conclusions rests entirely with the present author.)

The statistical prediction method is an attempt to derive empirically a simple computational scheme for a system governed by highly complex non-linear physical interactions. The limitations to predictability when a purely statistical method is used are severe.

The statistical prediction equation is of the form

$$Y_t = F\,(X_1, X_2, X_3, \ldots X_n)_{t=0}$$

Where Y_t is the predictand at some future time t, and the X_i are the predictors measured at some past time, say $t = 0$; the form of the empirical function F can be completely general.

The function F must be defined over an n-dimensional space, each point of which must be filled with a measured data point. The n-dimensional space may

be imagined to be made up of compartments, each defined by simultaneous measurements of each of the X_i dependent variables. The task of mapping the function over the n-dimensional space consists of filling each compartment with at least one measurement and fitting a mathematical function identically at each point.

If the equation has n independent variables, each having k discrete values, then there are $N = (k)^n$ compartments in the hyperspace. For example, if we are dealing with an equation with 6 variables, each with 6 classes, then $N = (6)^6 = 46{,}656$, a number which represents 60 years of data at two observations per day.

Of course, filling all of the compartments is much more difficult if the X_i are not independent, or if the data contain errors which must be reduced by smoothing over several observations. Hence, in actual statistical prediction schemes, available data samples will describe a complex process over only a small portion of the domain of its existence. To make the statistical prediction systems work it is necessary to employ statistical analysis procedures which are actually curve fitting techniques which interpolate across the vast number of empty compartments in the n-dimensional predictor space. Generally these are linear functions, or a simple low degree polynomial chosen through mathematical considerations rather than as representations of physical atmospheric processes.

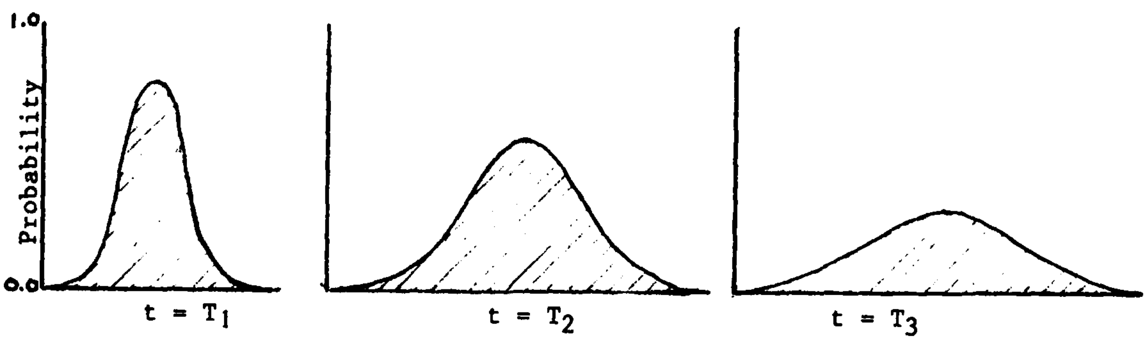

Figure 7. An illustration of the decay of information with forecast period (from Roberts 1971).

Let us assume that the output of a prediction is the specification of a probability function of some phenomenon in the positive time axis (Fig. 7). At each future time, T_i, the prediction yields some probability function. As

time increases, the spread of the probability function increases until it approaches the limiting "climatological" probability function.

The information provided by the prediction is inversely related to the spread of the probability distribution. When the probability distribution reaches its limiting function the information content is identical to that provided by estimation based on the statistical compilation of past observations. That is, the limiting or minimum information content at any time T_i is the product of the "objective statistical probability predition" method of forecasting. It is possible to make a "prediction" with even lower information content; simply forecasting zero change, or persistence, is one way. But a persistence forecast is actually a mild form of misinformation -- a statement made in the absence of new information given undue weight because it is "official". By calling on past weather records through some "objective" statistical scheme, the average forecast score is demonstrably improved over a forecast of persistence (in most cases), and we have become accustomed to accept this minimal performance level as the operational norm.

Some statistical prediction schemes are better than others, either because they include more past history; that is, they use more predictors, or have more of their data compartments filled, or they predict those weather elements which are less variable in the short term. Nevertheless, the ultimate limitations of the statistical prediction method are unavoidable; it simply is not possible to include all possible cases and all possible predictors in such amodel. This situation is not basically different in meteorology than it is in other scientific fields. Tradiationally, as soon as enough data have been collected and analyzed to permit scientists to formulate fundamental physical laws in the form of time-dependent mathematical equations, then models using these equations are preferred over statistical models. The physical model, or dynamical

analysis, approach is more general and more powerful because it can encompass all possible cases even if they have not previously occurred.

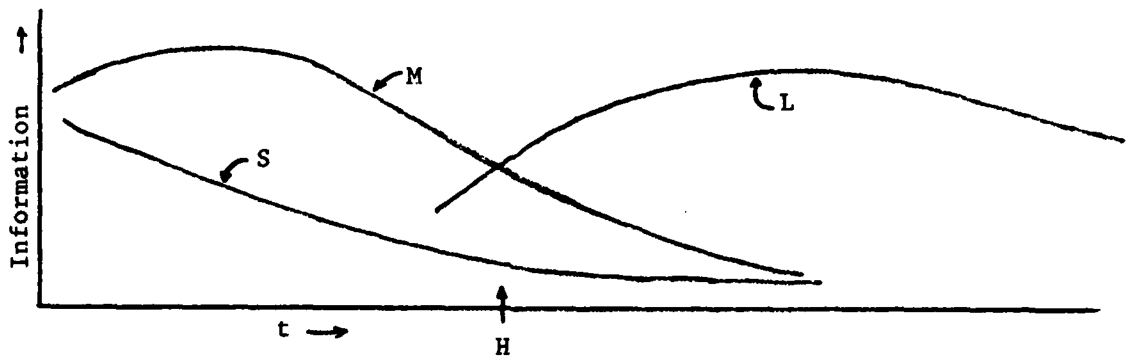

Figure 8. An illustration of information content of forecasts.

At any time T_i there is a probability distribution with a particular information content determined by the statistical compilation of past observations (curve "S" in Figure 8). This is the limiting case produced by the objective statistical probability prediction method of forecasting. Improvement in the information content of the forecast must come from dynamic physical analysis and prediction. At present this is available from the GWC for longer term forecasts generated by the synoptic scale numerical models (curve "L" in Figure 8). However, because of limitations of the model, of the data base, and the time lag required to collect data, process it, and to produce and distribute the forecast, there is a minimum time period H below which the synoptic scale forecast does not add information beyond that provided by the statistical compilation. For periods less than H hours improvement over the limiting statistical function (curve "M" in Figure 8) must come from mesoscale dynamic physical analysis and prediction by a system which receives and processes high density data at high speed.

DATA PROCESSING

For convenience we have divided the tactical Battlefield Weather Observation and Forecast System (BWOFS) into three subsections: data sources, data processing, and forecasting. Of the three parts of BWOFS, we have already discussed the forecasting method in some detail, and shown that subjective, dynamic analysis and prediction is the preferred method. This section is a brief discussion of the data processing sub-system. The data sources, especially satellite sensors, are treated in the main body of the report.

The Ad Hoc Panel on Mesoscale Processes of the Committee on Atmospheric Sciences, the National Research Council's watchdog committee for meteorological R&D matters, recently issued a short report on the status of mesoscale weather matters in the U.S. (NRC 1981). The section of that report dealing with "Data Processing, Analysis, and Interpretation" read in part:

> "As noted above, advanced data-processing and display techniques have become an essential and integral part of most remote-sensing observation systems. This is true both for image processing and manipulation and for quantitative computations (e.g., specifying the location, calibration, and mathematical 'inversion' of multispectral radiometric or Doppler radar and lidar data). These techniques are well advanced and are now used routinely to process vast volumes of data in real time.
>
> "At this stage in our conceptual and theoretical understanding of mesoscale weather systems and their structure and dynamics, it is difficult to analyze and interpret completely a comprehensive set of observational data. However, interactive data processing and display tools greatly simplify the task of synthesizing the information content of various meteorological fields and cloud and radar imagery. Reduction to common scales and formats, analysis and time-lapse or 'animated' displays, three-dimensional perspectives, and other processing techniques facilitate human interpretation of the data. Fast access to a comprehensive data base, coupled with versatile analysis and display software and hardware, allows adaptive exploration of physical hypotheses by interactive analyses.
>
> "The capability to assimilate and interpret the massive array of observational data quickly is particularly critical to operational applications such as mesoscale weather warnings and forecasts. At present, NWS forecasts at most field offices are unable to extract routinely the mesoscale information content of even the existing data sources, especially satellite and radar data. However, an immediate improvement in warnings and short-range forecasts is possible using existing technologies ..."

It is regrettable that the development of meteorological satellites preceded the development of man-computer interactive data processing and

display systems by nearly 15 years. The first low orbit meteorological satellite provided TV snapshots of the atmosphere which were at the same time greatly revealing and difficult to use. The top-side view of clouds provided new information which filled in data-sparse areas and which aided in analysis of large scale features in data-rich areas. However, the geometry of the images differed from that of maps, and unless landmarks could be recognized in the pictures it was not possible to locate weather information accurately. The advent of line-scan sensors to replace the TV cameras helped by combining separate pictures into a continuous image strip, and DMSP images were partially rectified to bring them into better relationship to map geometry. Nevertheless, most of the useful information in satellite images was inaccessible to the operational forecaster, and could be extracted by research meteorologists only by spending great amounts of time and patience in the process.

When the first meteorological satellites were flown, two modes of readout were provided. Images of the area around the local station could be received directly by any station having the necessary set of fairly simple and inexpensive equipment. The global data set could be read out at a few stations for use at a central processing center. Present DMSP and TIROS satellites still have both readout modes for image data, but they require more elaborate ground equipment. At first, most NWS weather stations, and some AWS base weather stations, were furnished direct readout, Automatic Picture Transmission (APT) equipment, and some stations were upgraded later to the more expensive sets. However, with the advent of the geosynchronous orbit satellites, the NWS opted for centralized readout and data processing with redistribution via land line to local forecast offices. Most, if not all, of the direct readout equipment was allowed to fall into disuse. Until last year the AWS had made no provision for satellite images at base weather stations except for those overseas stations which had DMSP Transportable Terminals (Transterms) in their vicinity. One can only speculate, of course, but if the ground data handling system had been based on computer-assisted video displays rather than teletype, facsimile receivers and hard copy posted on the walls when the satellites went up, it is most likely that a far better capability for mesoscale analysis and prediction would be found in weather stations today.

Successful operation of the first spin-scan imager in geosynchronous orbit on ATS-1 launched in December 1966 increased the volume of image data so greatly

that it soon became obvious that it was impractical to process and store the information in the form of photographic hard copy. At the same time, the images from the spin-scan camera were found to be geometrically stable and distortion-free so that it was possible to locate each picture element precisely in earth coordinates. The first demonstrations of accurate "navigation" of geosynchronous satellite data by computer were made at the University of Wisconsin in 1970 (Smith and Phillips 1972). Within a few years the photo copies were replaced by video displays; mechanical manipulation was supplanted by electronic controls; and measurement was made more accurate and much faster with computer assistance. With the addition of a disk recorder, the first Man-computer Interactive Data Accessing System (McIDAS) evolved (Smith 1975, Chatters and Suomi 1975). Since that time many others have made similar systems (Norman 1977, Serafin 1977, Smith 1977, Saker 1981, Beran and MacDonald 1981, Woick 1980, Cayla and Pastre 1980), each somewhat different. The concepts for the design and use of man-computer interactive systems are well understood and accepted in most of the meteorological research community.

The amount of useful information, both qualitative and quantitative, that an analyst can extract from satellite images is greatly increased when a man-computer interactive system is used. Also, the useful information can be extracted and used at high speed. Almost instantly images can be enlarged or reduced in scale, enhanced in monochrome or color, overlaid, mixed, sequenced, annotated, combined with radar images, surface or upper air observations; cloud motions and heights can be measured; and a very large number of graphics derived from all available data sources can be superimposed on the satellite images in precise registration. All of these things can be done with images from either the low orbit or the geosynchronous orbit satellites.

If systems like McIDAS are so good, why haven't they been snapped up by the services and put into the weather stations? It is worthwhile to explore this question briefly because it may point out some problems which must be overcome to obtain BWOFS. Many factors are apparent:

1. The technology is still new and still being developed. Not many persons responsible for operational services have had a chance to work with an advanced interactive system like McIDAS.

2. Most of the interactive systems which exist now were developed to support research scientsits and may not be optimally responsive to the needs of an operational forecaster which are not well defined yet.

3. The bias toward centralized data processing is still strong in both services. Thirty years of central processor advocacy cannot be reversed overnight. The Satellite Data Handling System (SDHS) which the Air Force tried to procure for AWS did include many interactive concepts, but it was to be solely for the GWC.

4. To date, McIDAS type systems have been built only by university laboratories. There are a great many video display terminals on the market and even some image processing systems, but so far only one company has demonstrated the competence to build a McIDAS.* Both the AFOS and SDHS procurements demonstrated the incompetence of large American companies in this field.

The movement of the McIDAS technology into the operational forecasting services has been slow but is gaining momentum. Systems have been put into operation effectively in NESS to navigate the GOES images operationally, and a second system is being delivered to provide flash flood forecasts. Television station WTVT, Tampa, Florida, used a McIDAS to assemble data and generate broadcast quality graphics (Leep 1981). Hauser (1981) uses a McIDAS system to provide a mesoscale forecasting service to farmers in Northern California. Many other man-machine systems are in use in government and university research laboratories.

In March 1982 the Centralized Storm Information System (CSIS) was delivered to the NWS Severe Storm Forecast Center to produce operational forecasts (Anthony et al. 1982). The CSIS procurement is an excellent example of how an operational agency should proceed to obtain a state-of-the-art system at minimum risk and minimum cost. For over a year, personnel of the Severe Storm Center used the University of Wisconsin McIDAS system through remote terminals before their equipment was assembled. Working with the system in their operational environment while producing operational forecasts gave them an excellent opportunity to explore its capabilities and to specify changes to optimize the CSIS for their application.

The software of the McIDAS system has been given to over 80 universities and other interested agencies in eleven countries. It has been adapted to run on at least seven different types of computers from large IBM machines to INTEL 8086 microprocessors.

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* IDETIK Corporation, Madison, Wisconsin, was started by engineers and programmers who had built most of the McIDAS's at the University of Wisconsin. IDETIK offers a version built around INTEL 8086 microprocessors with excellent capability, and including complete GOES data receiving equipment for $161,000.

At the NOAA Environmental Research Laboratories in Boulder, Colorado, the Prototype Regional Observing and Forecasting Service (PROFS) is being developed. The objective of PROFS is similar to that of BWOFS, except PROFS is to operate in the relatively stable and benign U.S. instead of a tactical battlefield. Beran and MacDonald (1981) defined the mesoscale forecasting service PROFS is to provide by contrasting its features with those of the more familiar synoptic forecasting service as shown in Table 7.

CHARACTERISTIC	SYNOPTIC	MESOSCALE
Forecast lead time	6-72 hours or more	0-12 hours
Area of Coverage	Global	Site-specific
Observations:		
Time	Hours	Minutes
Distance	Thousands of Km	Tens of Km
Data Volume	10^6 bits/hr	10^8 bits/hr
Data Flow Rates	Slow (mins to hrs)	Rapid (secs to mins)
Forecast method	Numerical Statistical, Patterson	Single cell Extrapolation Subjective & meso-models
Dissemination	Slow, passive	Rapid, active, and passive

Table 7. Comparison of Forecast Systems (from Beran and MacDonald 1981).

The method being used to develop PROFS is unusual in attempting to evaluate a large number of data sources, data handling techniques, and forecasting techniques as objectively as possible through comparative forecasting exercises. The first of these, the 81 Displaced Real-Time Test (DRT) was recently completed. During the 81 DRT forecaster work stations from AFOS, McIDAS, and POWS (an in-house system assembled by ERL) were used to compare various data handling and analysis techniques. As this is being written, the 81 DRT results have not yet been reported, but some interesting observations have been obtained from personal communications with PROFS development personnel. They have learned that it is extremely difficult to obtain truly objective results from a test series like 81 DRT because each test participant carries his prior experience and attitudes into the test. They learned that just teaching forecasters how to use the interactive equipment was not sufficient. A much longer period of familiarization and practice

was required before the forecasters developed confidence and motivation to use the equipment effectively. Once they had arrived at this level of mastery however, they became strong advocates for the new techniques.

The Swedish Weather Service is now embarked on a program which will completely re-equip all of its installations with a highly modular system which features man-machine interactive terminals for all forecasters and observers (Bodin 1981). The system, called Program for an Operational Meteorological Information System, or PROMIS-90, is designed to support observing and forecasting at all scales from the smaller end of the mesoscale with dimensions of 3 to 100 km and 0 to 2 hours, up to extended macroscale, 300 to 10^4 km and 36 hours to 10 days. The PROMIS-90 designers have drawn heavily on the McIDAS technology and on the NWS experience with AFOS. They intend to procure their system slowly, in increments, with full design control retained in the Swedish Meteorological and Hydrological Institute. They are extending the development-procurement period over a ten-year span purposely to provide time for their operational personnel to learn the new techniques and to adapt to the new operational concepts on a realistic schedule. PROMIS-90 resulted from an intensive series of studies which led to the conclusion that, "The present system is basically built on 19th Century technology and philosophy, and the additions and developments taking place after the second world war have not been integrated with their full impact in the present, today, weather service," (Bodin 1981). The process that led to recognizing that long held attitudes and practices had to be changed was called, " ... a painful experience which eventually led to something of great importance -- a design for a completely new concept of the future weather service."

The UK Meteorological Office has, after a decade of research started the FRONTIERS program (Saker 1981). FRONTIERS is the record breaking acronym for Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite. Its main objectives are (Browning 1979):

a. To combine radar, satellite, and synoptic weather data on an interactive graphics display to produce real-time analysis of rainfall.

b. To use those rainfall analyses to produce quantitative hourly rainfall forecasts for six hours ahead."

The FRONTIERS system was put into operation in 1979 on a highly "objective" basis, but it is now being modified extensively to make it possible for an experienced meteorologist to interact more effectively with the computer to edit and control the quality of the input data. It was found that the radar data especially required subjective analysis and correction to remove a lengthy list of inherent errors.

The purpose of FRONTIERS is narrowly limited to precipitation forecasting, and high speed is desired; therefore, the design of the display and its interactive controls has been optimized to that end. The operator has no keyboard; instead, all possible commands are listed on two small touch-sensitive video screens. The system can function in either experimental or operational mode. When in operational mode, no deviation from the preset menu is permitted, and the operator is required to complete each step within an allotted time interval. In the operational mode, a complete data edit, assembly, analysis, and forecast cycle is accomplished every 15 minutes.

As the NRC report quoted at the beginning of this section said:

> " ... advanced data processing and display techiques have become an integral part of most remote-sensing observation systems. This is true for both image processing and manipulation, and for quantitative computations (e.g., specifying the location, calibration, and mathematical 'inversion' of multispectral radiometric or Doppler radar and lidar data). These techniques are well advanced, and are now used routinely to process vast volumes of data in real time."

Mesoscale observing and forecasting systems are bei.g developed by many agencies and in each program, the only method of handling the required data rapidly enough to meet mesoscale needs has been found to be by using skilled meteorologists operating advanced man-computer interactive data accessing and display systems. The obvious conclusion is that the mesoscale forecasting system at the heart of BWOFS must be founded upon an adequate man-machine interactive data processing capability. We would like to state this more strongly:

> Important as the sensing systems are to BWOFS, they are secondary to a well developed, reliable, and highly flexible interactive data processing system. It does not matter what kind of radar, satellite, or in situ data are provided if they cannot be accessed and analyzed rapidly and completely enough to support an effective mesoscale forecasting service.

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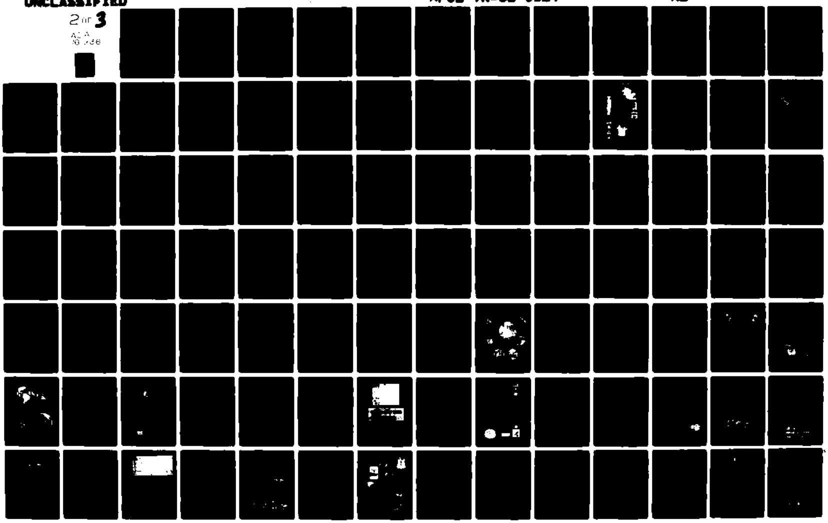

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AFGL	Air Force Geophysics Laboratory, Hanscom AFB, MA
AFOS	Automation of Field Operations and Services
ANMRC	Australian Numerical Meteorological Research Center
APT	Automatic Picture Transmission
AVHRR	Advanced Very High Resolution Radiometer (TIROS)
AWS	Air Weather Service
BWOFS	Battlefield Weather Observation and Forecast System
BWS	Base Weather Station (AWS)
CDA	Command and Data Acquisition Station (NOAA)
CDAS	Command and Data Acquisition Station (GMS)
CSIS	Centralized Storm Information System
DATTS	Data Acquisition, Telemetry, and Tracking Stations (Meteosat)
DCP	Data Collection Platforms (GOES)
DI	Dwell Imaging - a GOES operating mode
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DoC	Department of Commerce
DRT	Displaced Real-time Test, PROFS
DTRS	Data Transmission and Routing System (Meteosat)
ESA	Eropean Space Agency
ESOC	European Space Operations Center, Darmstadt, Germany
FEP	Front-End Processor (Meteosat)
FGGE	First GARP Global Experiment (also Global Weather Experiment

FRONTIERS	Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite
GARP	Global Atmospheric Research Program
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center (NASA)
GWC	Global Weather Center, AWS, Offut AFB
HIRS/2	High-resolution Infrared Radiation Sounder, Second Version (TOVS)
HIS	High-resolution Interferometer Sounder - a new concept
HRPT	High Resolution Picture Transmission (TIROS)
IAMAP	International Association of Meteorology and Atmospheric Physics
IR	Infrared
JMA	Japan Meteorological Agency
LOR	Lock-On Range
MCC	Meteosat Control Center (ESOC)
McIDAS	Man-computer Interactive Data Accessing System
MESOSAT	Mesoscale Weather Satellite - Civilian version of TACSAT
MGCS	Meteosat Ground Computer System (ESOC)
MIEC	Meteorological Information Extraction Center (ESOC)
MSC	Meteorological Satellite Center, Tokyo, Japan
MSI	Multi-Spectral Imaging (GOES)
MSU	Microwave Sounding Unit (TOVS)
NASA	National Aeronautics and Space Administration
NESS	National Earth Satellite Service

NMC	National Meteorological Center, NWS, Washington, D.C.
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NWS	National Weather Service, NOAA
OLS	Operational Line-scan System (DMSP)
OMB	Office of Mangement and Budget
PGM	Precision Guided Munition
PMP	Precision Mounting Platform (DMSP)
PRESSURS	Prestrike Surveillance/Reconnaisance System
PROFS	Prototype Regional Observing and Forecasting Service
PROMIS-90	Program for an Operational Meteorological Information System -1990.
SDB	Synchronous Data Buffer (GOES)
SDHS	Satellite Data Handling System
SEOS	Synchronous Earth Observatory Satellite - an obsolete concept
SMS	Synchronous Meteorological Satellite
SSH	Special Sensor H (DMSP)
SSEC	Space Science and Engineering Center, Madison, WI
SSM/I	Special Sensor Microwave - Imager (DMSP)
SSM/T	Special Sensor Microwave - Temperature sounder (DMSP)
SSU	Stratospheric Sounding Unit (TOVS)
TACC	Tactical Air Control Center (AF)
TACSAT	Tactical weather satellite - a new concept
TAF	Terminal Area Forecast
TAR	Target Acquisition Range
TOT	Time-Over Target

TOVS	TIROS Operational Vertical Sounder
Transterm	Tranportable Terminals for DMSP
TTS	Transportable Terminal System (DMSP); also Transterm
VAS	VISSR Atmospheric Sounder (GOES)
VISSR	Visual and Infrared Spin-Scan Radiometer (GOES)
WEFAX	Weather Facsimile
WETM	Weather Team (AWS)
WOC	Wing Operations Center (AF)
433L	A 1960 era AF program that failed as a "system development" but from which some good items of equipment evolved

APPENDIX A

DEFENSE METEOROLOGICAL SATELLITE PROGRAM

Information in this appendix was taken from Block 5D Compendium issued in January 1975 by the DMSP Program Office, Space and Missile Systems Organization, Los Angeles Air Force Stations, California. No later version of this document, nor superceding publication has been issued.

CONTENTS

DMSP KEY SYSTEM CHARACTERISTICS

Satellite Systems

Temperature Moisture Sounder
Gamma Detector
Electron Spectrometer
Other Special Meteorological Sensors
450 NM Sunsynchronous Orbits
One satellite has Early Morning Ascending Node (0700-0800 Local)
One satellite has Noontime Ascending Node (1130-1230 Local)
Visible and Infrared Imager

Ground Systems

Navy shipboard terminals receive direct data readouts over their areas
Dedicated Facilities for launch and early orbit checkout of satellites
Two readout stations for command and control
Synchronous communications satellite used as link to AFGWC
AFGWC is recipient of digital data for processing
Air Force and Navy tactical remote terminals are recipients of direct data readouts over their areas

Mission

Acquire meteorological data in visual and infrared spectra

- high-resolution (1.5 nm x 1.5 nm) global coverage
- very high-resolution (0.3 nm x 0.3 nm) coverage of selected areas
- near constant resolution versus scan angle

Transmit acquired data to Control Readout Stations in continuental U.S. and mobile ground stations and shipborne stations by command

Orbit

Circular sun-synchronous
Altitude: 450 $\pm$ 9 nautical miles
Period: 101 minutes
Apogee-to Perigee: 17 nautical miles
Inclination: $98.7^\circ \pm 1.3^\circ$
Sun angle: 0° to 95°

Payload

Meteorological sensors for tri-service users
- primary sensor (OLS) and electronics (OLS/AVE)
- up to six special meteorological sensors and electronics

Weight: 300 pounds
Power: 170 watts

Weight

Integrated satellite system
- on launch pad: 5850 pounds
- in orbit: 1032 pounds

Design

Maintain precision co-alignment of payload sensors
Precision pointing of co-aligned spacecraft/payload sensors axis to local geodetic vertical

Attitude Determination and Control

Zero momentum; three-axis stabilized; earth oriented

Primary system accuracy: 0.01°

Reference: three orthogonal strap-down gyros plus one skewed as backup
solid state optical star mapper

Control: three orthogonal reaction wheels plus one skewed as backup

magnetic momentum unloading coils

Power (Direct Energy Transfer System)

Power source: sun tracking deployable solar array

power storage: nickel-cadmium battery

primary bus: +28 volts regulated

power available: 300 watts average

Command and Control

SGLS compatible
Controlled command access period
Stored and real-time commands, maintained by redundant ground programmable CPU's

Central processing units
Stored commands: 800
2 processor memories - 16,000 words each
High accuracy time reference - redundant crystal oscillator

Structure (Modular Construction)

Precision mounting platform

- supports payload sensors and attitude determination components
- aluminum - dip-brazed construction
- co-alignment of sensors < 10 arc-sec

Equipment support module

- supports payload electronics, special meteorological sensors, spacecraft electronics
- aluminum frame and lightweight honeycomb panels

Reaction-control system structure

supports reaction control system and third stage solid motor

truss supported aluminum monocoque construction

Thermal Control: Combination of Passive and Active Components

Sensor control

Electrically controlled rectangular louvers plus make-up heaters

$\pm$ 1° C control

Spacecraft systems

Electrically controlled pin-wheel louvers

Make-up heaters thermal finishes and blankets

Communications

S-band command, data and telemetry links

Up-link

Redundant receiver-demodulator unit

1 KBPS uplink command rate

Payload data links

3 simultaneous S-band links

1024 to 2670 KBPS data rate each link

Telemetry down-link

S-band redundant transmitters

2 KBPS or 10 KBPS orbital data rate

OLS- Operational Linescan System

Meteorological data collected in visible and infrared spectra

Visible data collected as 0.3 nm x 0.3 nm during day and 1.5 nm x 1.5 nm at night

Infrared data collected as 0.3 nm x 0.3 nm at all times

Oscillating scanner collects data in both directions along 1600 nm swath

Near constant resolution as a function of scan angle

Three digital tape recorders for data storage

Each recorder can store 20 minutes of interleaved visual and infrared 0.3 nm x 0.3 nm of data

Analog filtering and digital averaging used to smooth data to 1.5 nm x 1.5 nm for on board global storage

Each recorder can store 400 minutes of interleaved visual and infrared 1.5 nm x 1.5 nm of data

Telemetry and special meteorological sensor data included within primary smoothed data stream

Real time encrypted transmission of 0.3 nm and 1.5 nm data

THE 5D SPACECRAFT

The Block 5D spacecraft is an "integrated spacecraft" in that specific functions of a launch vehicle upper stage have been integrated into the satellite. In particular, the Block 5D spacecraft provides ascent phase guidance for the launch vehicle from lift-off through orbital insertion as well as upper stage electrical power, telemetry, and attitude control. The spent third stage propulsion and reaction control systems are carried into orbit. The configuration affords considerable weight savings over the conventional booster/ spacecraft configuration. This savings has been reallocated to provide selective redundancy of life limiting components of the spacecraft. The integrated spacecraft was also designed with an expanded power subsystem to meet payload requirements.

The major structural sections of the spacecraft are: (1) a precision mounting platform (PMP) for mounting sensors and other equipment requiring precise alignment, (2) an equipment support module (ESM) which encloses the bulk of the electronics, (3) a reaction control equipment (RCE) support structure (RSS) which contains the spent third stage rocket motor and supports the reaction control equipment, and (4) a sun tracking solar cell array. The design of a precision mounting platform in combination with an equipment support module allows for an increase in spacecraft capacity for redundant equipment, thereby improving system reliability. The spacecraft is capable of supporting 300 lbs of sensor payload on orbit, of which 95 lbs is allocated for special sensors. The nominal on-orbit spacecraft weight is 1032 lbs.

A highly accurate attitude determination and control subsystem (ADACS) permits precise pointing of the primary imaging sensor (The OLS - Operational Linescan System). The subsystem includes three orthogonal gyroscopes which measure short-term changes in attitude while a star sensor provides long-term update to bound effects of gyro drift. The desired attitude is computed based upon star catalogs and ephemeris tables uplinked to the spacecraft central processor unit on a periodic basis.

A separate backup attitude determination subsystem on the Block 5D spacecraft provides attitude control about one-tenth as good as the primary system. This subsystem consists of a solid state earth sensor assembly which provides pitch and roll information to the central processor, and a sun sensor which in conjunction with the gyro package provides yaw information. The software programs for both primary and backup attitude determination are resident in each of two full redundant central processor units.

Three-axis attitude control is maintained in the orbital configuration by automatic momentum exchange between three momentum wheels. On-board magnetic coils provide controlled interaction with the earth's magnetic field to prevent the accumulation of wheel secular momentum. Operation of these coils is under the control of the closed-loop spacecraft attitude control system. Both the momentum wheels and gyros are backed up by a fourth skewed unit for redundancy.

A closed-loop on-board, digital system provides ascent phase guidance. Ascent phase attitude is determined by three orthogonal accelerometers and the same three orthogonal strapped-down gyros used for orbital attitude determination. Outputs from these inertial measurement devices are processed by one of

the on-board central processors to determine inertial position, attitude and time derivatives. The guidance portion of the on-board ascent phase software computes a new trajectory each half-second based upon computed position and velocity errors, and a description of the desired final orbit and issues appropriate steering commands.

Ascent phase attitude control is accomplished through a combination hot and cold gas reaction thruster array. The hot gas system uses hydrazine as a mono-propellant. Each of the four pitch/yaw hydrazine thrusters produces 155 lbs of vacuum thrust and can be reduced on command, to 65 lbs thrust. The high thrust mode is used for first stage separation thrusting and attitude control during second stage burn. The low thrust mode is used for second stage separation, attitude control during third stage burn, and the final velocity trim maneuver. A cold gas nitrogen system provides low level thrusting for attitude control during coast phases.

The primary functions of the command and control subsystem are to process the uplinked spacecraft and sensor commands, to monitor/control the operating configuration of the various spacecraft equipments, and to provide clock signals for all spacecraft functions. The heart of the subsystem consists of two fully redundant high speed, digital central processing units. Although these units are part of the command and control subsystem, they perform the additional functional requirements of boost guidance support, primary orbital attitude determination and control, backup orbital attitude determination and control, and solar array orientation control. The central processor programs are loaded in the spacecraft memory and can be changed by uplinked commands, if necessary, during orbital operations.

The spacecraft command and control subsystem accepts sensor commands as well as spacecraft commands and routes valid sensor commands to the primary sensor for further processing within its central processing unit.

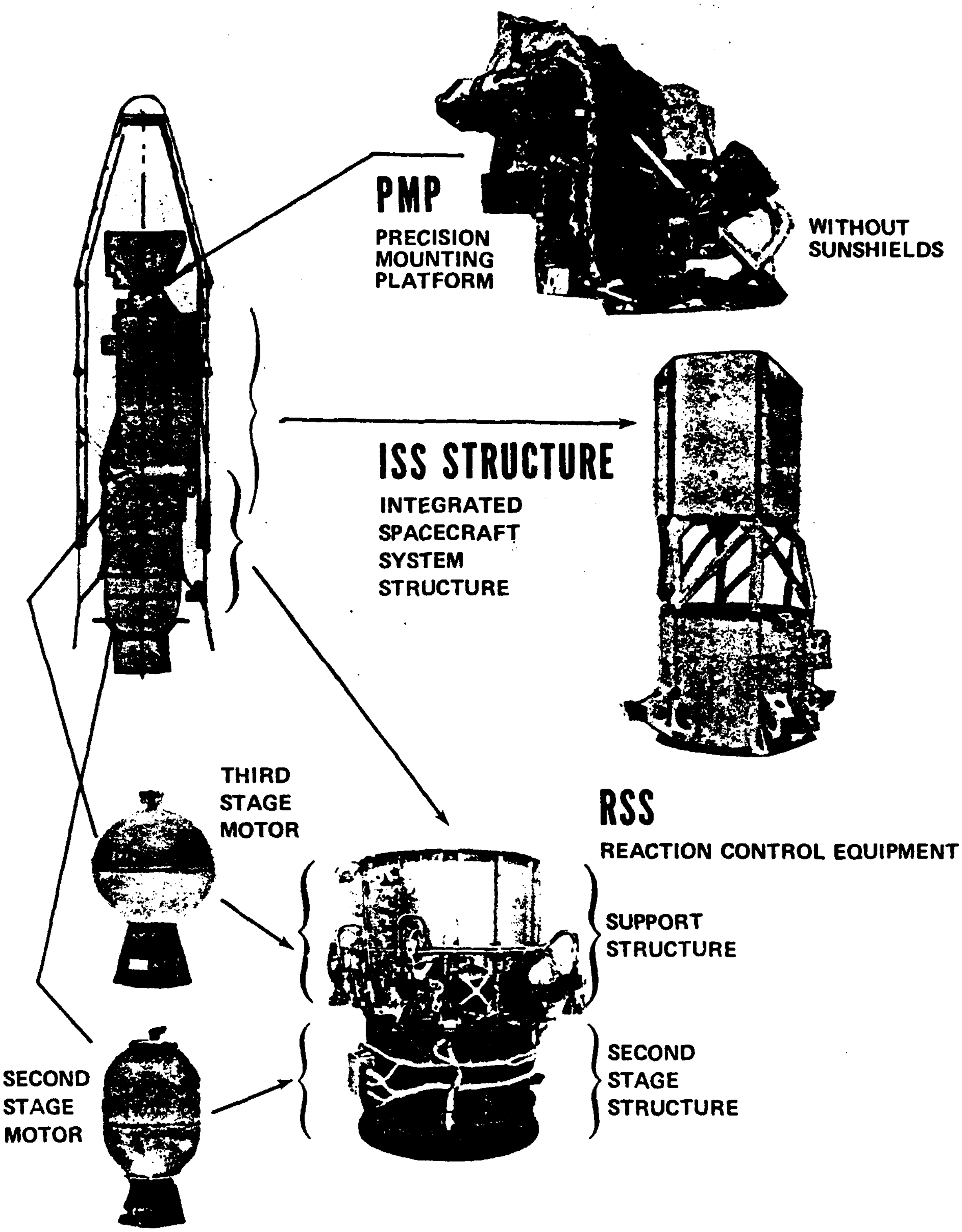
The power subsystem is a direct energy transfer system. The Block 5D solar cell array is a planar array that is rotated about one axis to track the sun. Power from the solar cell array is either conditioned for direct use by the spacecraft components, stored in a nickel-cadmium battery, or shunted through resistive power dissipators on the array. The sun attitude is computed from ephemeris data in the central processor. The solar array is deployed and erected following spacecraft orbital injection. The direct energy system is capable of supporting loads requiring 290 watts of orbit average power.

The communication subsystem consists of two functional groups: the data transmission group, and the telemetry/receiver group.

The data transmission group consists of three S-band transmitters and three earth-oriented antennas, two of which are cross-strapped for redundancy. The data rates for real time data are 1.024 megabits per second (mbs) and for stored data 1.3312 or 2.6624 mbs.

Dual redundant S-band transmitters are provided for equipment status telemetry. One radiates through a pair of bifilar antennas which provide spherical coverage, allowing all-attitude telemetry communication with the ground sites, and the other radiates through an S-band antenna identical to the earth-oriented data antennas. These transmitters can be used in a backup mode for transmitting sensor data.

CONFIGURATION



The receiver/demodulator is a redundant S-band unit which is used to receive both command data and central processor programming data for the spacecraft and the primary sensor. The uplinked signals are received through the bifilar omni-antennas. The uplink command rate is 1 kilobit per second (kbs).

The thermal control subsystem protects all spacecraft components from potentially damaging thermal extremes. The precision mounting platform is carefully controlled to eliminate thermal gradients which could cause distortion and resulting sensor misalignment.

Passive thermal control techniques include the use of selected finishes, first and second surface radiators, and insulation blanketing. Active control requiring heat addition is accomplished with strip heaters. Active control requiring heat rejection is accomplished by placing variable geometry louvers in the radiator's cold space field-of-view.

THE OPERATIONAL LINESCAN SYSTEM (OLS)

The OLS is the primary imagery data acquisition system on the Block 5D spacecraft. This system gathers visual and infrared imagery data from earth scenes and provides such data, together with appropriate calibration, indexing, and other auxiliary signals, to the spacecraft for transmission to ground stations. The data is collected, stored, and transmitted in fine (F data) or smoothed (S data) resolution. The OLS has a scanning optical telescope system driven in a sinusoidal motion by counter-reacting coiled springs and a pulsed motor. This motion moves the instantaneous field-of-view of the detectors across the satellite subtrack, with maximum scanning velocity at nadir and reversals at end of scan. Detector size is dynamically changed to reduce angular instantaneous field-of-view as it nears each end of scan, thereby maintaining an approximately constant footprint size on earth. The swath width is 1600 nm from a nominal altitude of 450 nm.

The optics consist of a cassegrain telescope, whose elements are common to both visual and infrared imagery, and a set of relay optics that separates the wavelengths and fields-of-view for the different detectors. On-board preprocessing of the data by the OLS provides for the various modes of data output. The OLS provides global coverage in both visual (L data) and thermal (T data) modes. Fine resolution data is collected continuously , day and night, by the infrared detector (TF data) and continuously during daytime only by a segmented, silicon diode detector (LF data). Fine resolution data has a nominal linear resolution of 0.3 nm. Tape recorder storage capacity and transmission constraints limit the quantity of fine resolution data (LF or TF) which can be downlinked from the stored data fine (SDF) mode to a total of 80 minutes of LF and TF data per ground station readout.

Data smoothing permits global coverage in both the infrared (TS) and visible (LS) spectrum to be stored on the tape recorders in the stored data smoothed (SDS) mode. Smoothing is accomplished by electrically reducing the sensor resolution to 1.5 nm in the along scan direction, then digitally averaging five such .3 x 1.5 nm samples in the along track direction. A nominal linear resolution of 1.5 nm results. 400 minutes of LS and TS data may be downlinked

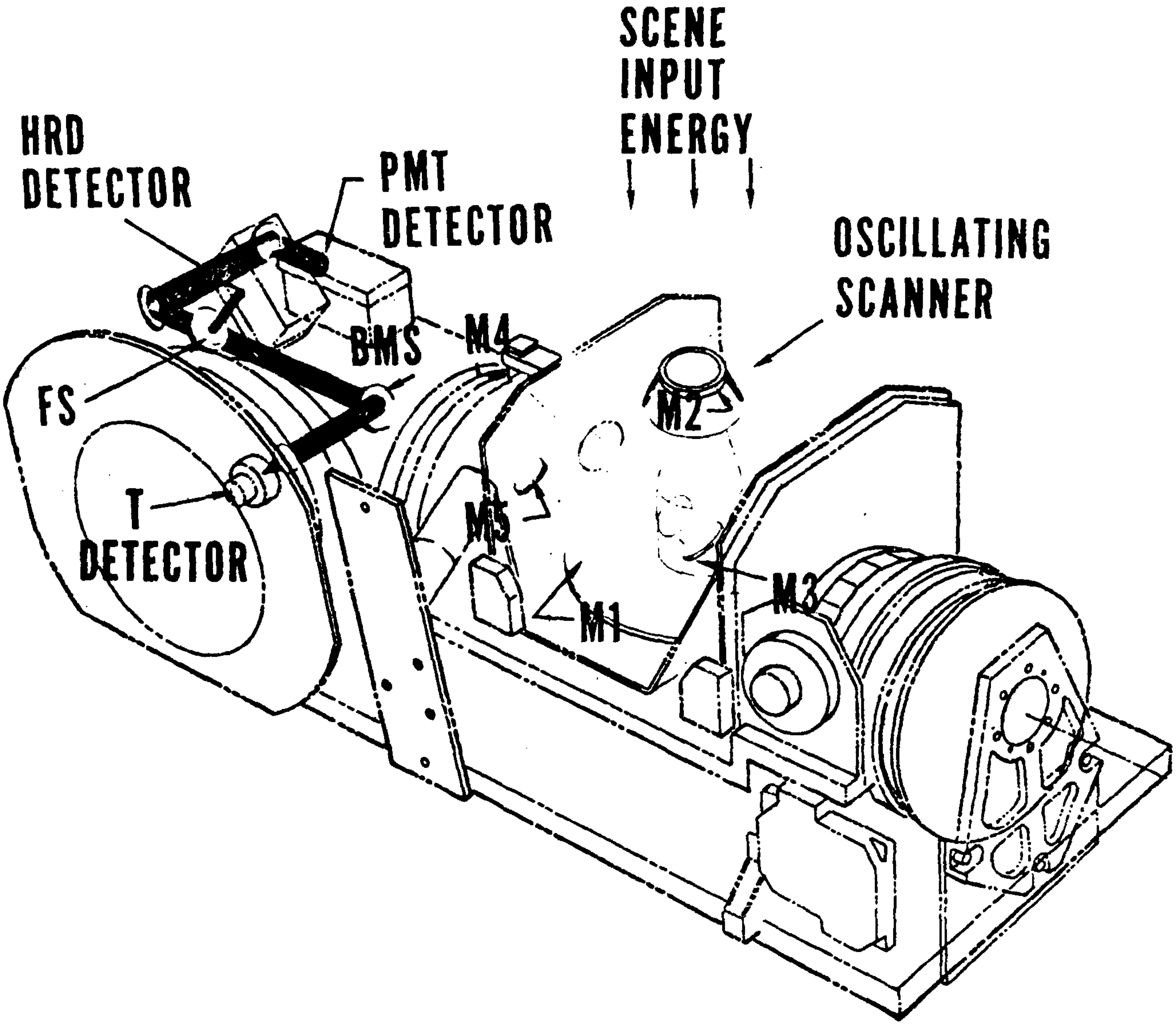
in a single ground station readout. An additional detector allows collection of visible data (LS) with a 1.5 nm nominal linear resolution under low light level conditions. In the fine mode visual (LF) channel, a 3-segment silicon diode detector is switched at ±400 nm from subtrack, using either of two segments from that point to end of scan. All three segments are used and summed together within 400 nm of nadir. Detector geometry and segment switching compensate for the optical rotation of the field-of-view, as a function of scan angle. A mirror in the telescope assembly is dynamically driven to accomplish image motion compensation by removing the satellite's along track motion of the instantaneous field-of-view to preserve scan line contiguity. The visual daytime response of the OLS is in the spectral range of 0.4 to 1.1 microns; chosen so as to provide maximum contrast between earth, sea and cloud elements of the image field. The visual fine mode is provided for day scenes only. The infrared detector, consisting of two segments, is switched at nadir to provide approximately constant ground footprint and image derotation. The detector is a tri-metal (HgCdTe) detector operating at approximately 105°K. The OLS infrared spectral response of 8 to 13 microns was chosen to optimize detection of both water and ice crystal clouds. The sensor output is normalized in terms of the equivalent blackbody temperature of the radiating object. A shaping network is employed to change the fourth-power-of-temperature response of the detector so that sensor output voltage is a linear function of scene temperature. This detector is passively cooled by a radiative cooler viewing free space. The tri-metal detector is accurate to within 1°K rms across the (equivalent blackbody) temperature range 210°K to 310°K. The noise equivalent temperature difference (NETD) of the infrared system is well within 1°K across this same range.

The OLS data processing subsystem performs command, control, data manipulation, storage, and management functions. Commands are received from the ground through the spacecraft command system, stored in the OLS and processed by the OLS according to time codes. The OLS executes commands, accomplishes the smoothing of fine resolution data, derives gain commands from orbital parameters for normalization of visual data and dynamic signal control, and outputs the data to the spacecraft communications system. All data is processed, stored and transmitted in digital format. The OLS also provides the data management functions to process, record and output data from up to six additional meteorological sensors.

A combination of either fine resolution data and the complementary smoothed resolution data (i.e., LF and TS or TF and LS) can be provided in the direct digital transmission mode. Either encrypted or clear direct data can be output simultaneously with two channels of stored data. The OLS system includes and controls three digital tape recorders, each with a storage capacity of 1.67 x 10^9 bits. Each recorder can record at any one of three data rates and play back at either of two data rates. These rates are:

INPUT	STORAGE (per recorder)
66.56 Kbps (LS and TS interleaved bit by bit)	400 minutes
1.3312 Mbps (LF and TF interleaved bit by bit)	20 minutes
665.6 Kbps (LF or TF only)	40 minutes

OLS - SENSING CONCEPT



M1, M2, M3, M4, M5 : PRIMARY MIRRORS

BMS: BEAM SPLITTER; SPLITS INFARED ENERGY FROM VISIBLE ENERGY VIA MTI AND MT2 (NOT SHOWN) TO THE T (THERMAL) DETECTOR.

FS : FIELD SPLITTER; SPLITS FIELD OF VIEW OF VISIBLE ENERGY FOR THE VISIBLE DETECTORS.

HRD: HIGH RESOLUTION DIODE (SMALL FIELD OF VIEW).

PMT: PHOTO MULTIPLIER TUBE (LARGER FIELD OF VIEW).

OUTPUT	TIME/DATA
2.6624 Mbps	10 minutes/All LS and TS
2.6624 Mbps	10 minutes/All LF and TF
1.3312 Mbps	20 minutes/All LF or TF

All tape recorders are interchangeable in function, providing operational redundancy and enhanced system life expectancy.

SPECIAL SENSORS

(SSD) Atmospheric Density Sensor

The Atmospheric Density Sensor (SSD) will provide a measure of major atmospheric constituents (Nitrogen, Oxygen and Ozone) in the earth's thermosphere (100 to 250 Km in altitude) by making earth-limb observations of the ultraviolet radiation from this atmospheric region. The sensor will measure the radiation emitted in the ultravioletspectral region from excitation of molecular nitrogen by impinging solar radiation. The intensity of the emitted radiation is proportional to the excitation rate and the number of molecules at any given altitude. Funneltrons and a photomultiplier tube will detect the radiation after it passes through a collimator which provides a 0.1 x 4.0° field-of-view. The SSD will be mechanically driven to scan vertically through the earth's limb in about 30 seconds. The instrument will provide approximately 50 sets of density profiles on the daylight portion of each orbit. The SSD is currently under development.

(SSJ) Precipitating Electron Spectrometer

A small, lightweight (3lb) sensor, the SSJ counts ambient electrons with energies ranging from 60 eV to 20 KeV. Utilizing a time-sequenced variable electrostatic field to deflect the particles toward the chaneltron detector, the sensor determines the number of electrons having energies within certain sub-ranges of the 60 eV to 20 KeV spectrum.

(SSH) Temperature/Water Vapor/Ozone Radiometer

The SSH, a scanning infrared radiometer, will provide global data which yields vertical temperature profiles, vertical water vapor profiles, and total ozone concentration.

(SSB) Gamma Detector

The SSB is a gamma radiation measurement sensor provided to DMSP by AFTAC.

SPECIAL SENSOR H (SSH)

The Defense Meteorological Satellite Program (DMSP) Block 5D satellite will contain an infrared multispectral sounder for humidity, temperature, and ozone. The SSH provides soundings of temperature and of humidity, and a single measurement of ozone for vertical and slant paths lying under and to the side of the sub-satellite track.

The SSH makes a set of radiance measurements in narrow spectral channels lying in the spectroscopic absorption bands of carbon dioxide, water vapor, and ozone. These radiance measurements are mathematically inverted to yield vertical profiles of temperature and of water vapor and an indication of total ozone content. The radiative transfer equation expresses upwelling radiance in each spectral channel as a function of the vertical temperature profile, the vertical compositional profile, and spectroscopic transmission functions. Transmission functions have been developed from laboratory and field measurements, correlated by molecular theory, and complied. Several inversion techniques have been developed to provide approximate solutions to the radiative transfer equation, yielding either the temperature profile or the compositional profile if the other profile is known.

For temperature sounding, radiances are measured in channels lying in channels lying in the wing of the 15 μm carbon dioxide absorption band. CO_2 is taken to have a constant mixing ratio or other assumed vertical compositional profile. Solution is then made to yield the vertical temperature profile.

For humidity sounding, channels are selected to provide a range of absorption coefficients in the rotational water vapor band. The vertical temperature profile is available from simultaneously measured data as described above. The inversion therefore yields the vertical humidity profile.

The temperature profile is necessary as an input to obtain the humidity profile. The humidity profile can provide increased accuracy in the temperature profile determination by correcting for the water vapor absorption interfering in the CO_2 band. Because of the interactive effects it is advantageous that both CO_2 band and water vapor band radiances are measured by the same instrument and referred to the same reference sources as is done within the "H" package.

SPECIAL MICROWAVE IMAGERY SENSOR (SSM/I)

A special microwave imagery sensor will be flown on DMSP Block 5D-2 satellites in the mid 1980s. Called the SSMI (special sensor, microwave imagery), the sensor is a passive microwave radiometer that detects thermal energy emitted by the earth-atmosphere system in the microwave portion of the electro-magnetic spectrum.

Meteorologists at the Air Force Global Weather Central and the Navy's Fleet Numerical Oceanography Center will use SSMI sensor data to measure ocean surface wind speed, ice coverage and age, areas and intensity of precipitation, cloud water content and land surface moisture. An estimate of atmospheric attenuation at each of the SSMI sensor frequencies will also be available.

These data will be used for tropical storm reconnaissance, ship routing in polar regions, agricultural weather, aircraft routing and refueling, estimates of trafficability for Army support, communications management, and other missions.

Computer software to extract environmental elements from the SSMI sensor measurements was developed by prime contractor, Hughes Aircraft Company, based on scientific data supplied by Environmental Research and Technology, Inc., a subcontractor.

The SSMI will provide seven data channels of information; the resolution and the major environmental response of each channel depend upon its wavelength as indicated in the chart below:

Wavelength (mm)	Frequency GHz	Polarization	Resolution (km)	Environmental Response
15.5	19.35	V/H	50	Ocean Surface Wind, Land Surface moisture
13.5	22.235	V	50	Integrated Water Vapor Content, Ocean Surface Wind
8.1	37.0	V/H	25	Rain, Cloud Water Content, Ice Cover
3.5	85.5	V/H	13	Rain

The seven channels of the SSMI make it possible to judge several environmental elements when the channels are processed multispectrally using three principles.

First, the emissivity of natural surfaces depends, among other things, on the water content and roughness of the surface. This makes it possible to observe variations of surface moisture over the land and ice cover over the oceans. Wet surfaces, for example, have a low emissivity; that is, they radiate little energy in the microwave spectrum, despite their actual temperature. It is also possible to judge the surface roughness or the surface wind speed over oceans from the microwave brightness temperatures.

Second, the energy measured at the SSMI sensor wavelengths is very sensitive to cloud drops and rain drops in the atmosphere.

As in radars, energy at the shortest wavelength (3.5 mm) is most affected by atmospheric water droplets; energy at the longest wavelength (15.5 mm) is least affected by atmospheric water droplets. The 13.5 mm wavelength channel responds much more strongly to the integrated water vapor in the atmosphere than any other channel.

Third, microwave radiometers measure energy in either or both of two mutually perpendicular polarizations. Microwave energy emitted or reflected from surfaces like water or land, tends to be polarized. The energy measured in the two polarizations is much different. The amount of difference depends upon the moisture content of the surface.

Energy from atmospheric phenomena like water vapor, clouds and rain clouds, tends to be unpolarized. Both polarizations are measured at all the SSMI sensor wavelength except 13.5 mm. These different effects on the energy emitted and reflected through the earth's atmospheric system provide a unique signature for many different phenomena, permitting their detection and measurement from space.

TACTICAL GROUND STATIONS

Program Transportable Terminal Systems (TTS, also TRANSTERMS) are deployed to those worldwide weather centers which provide support to major theater commands and to selected shipboard and land terminals. These self-contained tactical ground stations utilize real-time Block 5 data in direct support of Army, Navy, and Air Force field operations.

A TTS consists of an antenna with a programmed or automatic tracking capability and receiving, decryption, display and recording subsystems integrated into a mobile, transportable 30-foot enclosed semi-trailer van. The TTS display subsystem provides the capability for displaying visual or infrared data as a hard copy, transparent photographic positive. The recording subsystem enables the operator to reproduce, post-pass, real-time data for further processing. An emergency power source is provided at each site.

Six of the TTS contain an Antenna Protection and Environmental System (APES) for the environmental protection of the antenna/pedestal subsystem. The existing antenna/pedestal is remoted to a 12-foot enclosed tower and covered with a 19-foot rigid radome. This system insures continuous operational capability in high wind and severe cold environments.

The Transportable Terminal System RF, receiver, display, and recorder subsystems are able to process Block 5D RTD mode data received on one of two selectable frequencies.

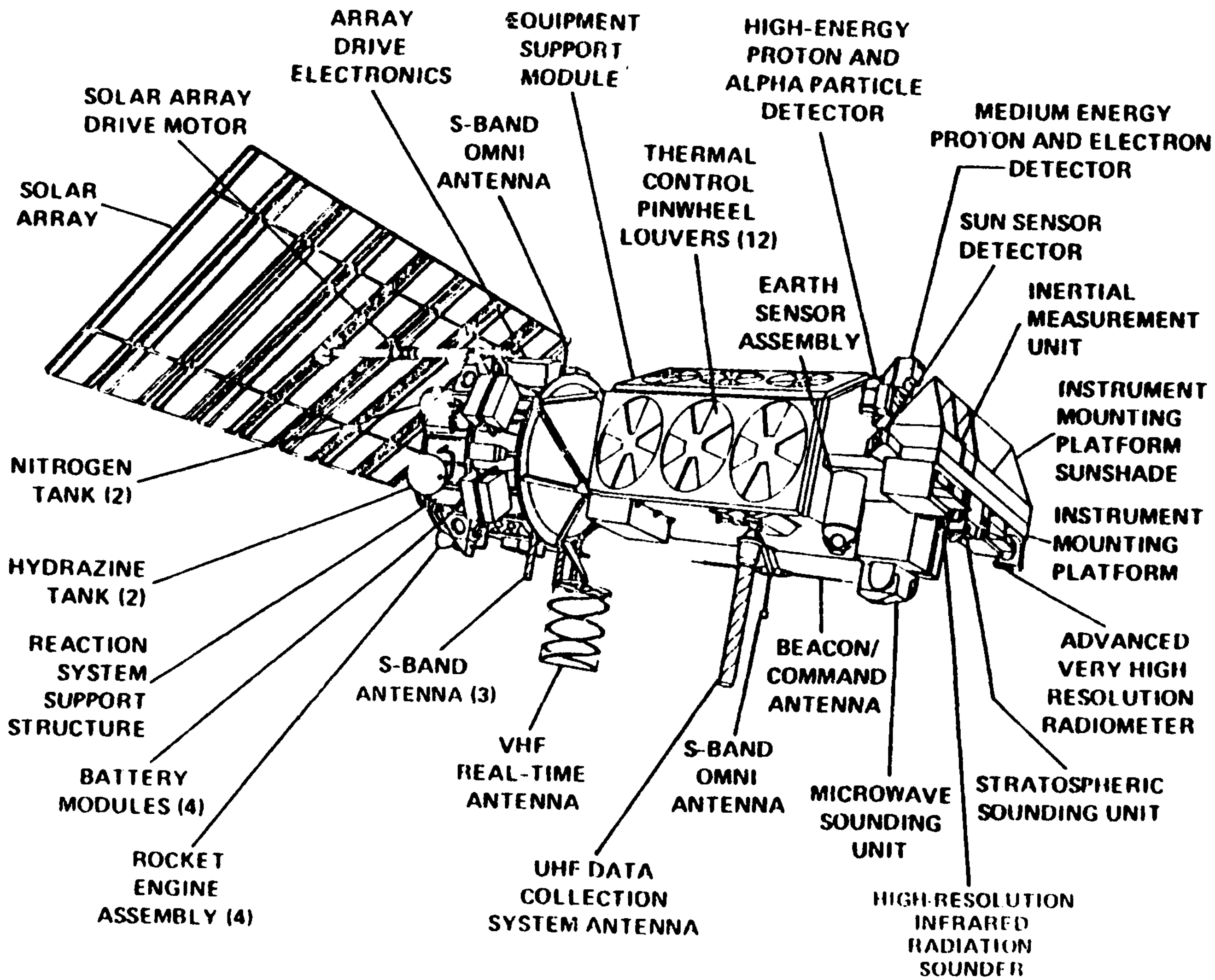
APPENDIX B.

TIROS-N Program

Information in this appendix was taken from NOAA Technical Memorandum NESS 107, "Data Extraction and Calibration of TIROS-N/NOAA Radiometer." November 1979, NOAA, NESS, Washington, D.C.

CONTENTS

TIROS-N Spacecraft



2. INSTRUMENTS

2.1 Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR provides data for transmission to both APT and HRPT users. HRPT data are transmitted at full resolution (1.1 km); the APT resolution is reduced to maintain allowable bandwidth. The AVHRR for TIROS-N is a scanning radiometer, sensitive in four spectral regions; a fifth channel will be added on later satellites in this series. Deployment of four- and five-channel instruments is as follows: four-channel instruments are planned for TIROS-N, NOAA-A, NOAA-B, NOAA-C and NOAA-E; five-channel instruments for NOAA-D, NOAA-F, and NOAA-G.

The APT system transmits data from any two of the AVHRR channels selected by command from the National Environmental Satellite Service (NESS) Spacecraft Operations Control Center (SOCC). The HRPT system transmits data from all AVHRR channels. To avoid future changes on the spacecraft and in the ground receiving equipment, the TIROS-N/NOAA series HRPT data format has been designed to handle five AVHRR channels from the outset.

When operating with a four-channel instrument, the data from the 11-micrometer (μm) channel are inserted in the data stream twice so that the basic HRPT data format is the same for both the four- and five-channel versions.

Table 2-1 lists the spectral characteristics of the four- and five-channel instruments and designates the spacecraft on which they are planned to be deployed.

Table 2-2 is a listing of the basic AVHRR parameters.

2.2. TIROS Operational Vertical Sounder (TOVS)

The TOVS provides data for transmission to both HRPT and DSB receiving stations. The data are transmitted in digital format at full instrument resolution and accuracy.

The TOVS consists of three independent instrument subsystems from which data may be combined for computation of vertical atmospheric temperature and humidity profiles. These are:

a. High resolution infrared radiation sounder mod. 2

b. Stratospheric sounding unit

c. Microwave sounding unit

Table 2-1. Spectral characteristics of the TIROS-N/NOAA AVHRR instruments

Four-channel AVHRR, TIROS-N				
Ch 1 0.55-0.9 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.5-11.5 µm	Ch 5 Data from Ch 4 repeated
Four-channel AVHRR - NOAA-A, -B, -C, and -E				
Ch 1 0.58-0.68 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.5-11.5 µm	Ch 5 Data from Ch 4 repeated
Five-channel AVHRR, NOAA-D, -F, and -G				
Ch 1 0.58-0.68 µm	Ch 2 0.725-1.1 µm	Ch 3 3.55-3.93 µm	Ch 4 10.3-11.3 µm	Ch 5 11.5-12.5 µm

Note: Changes to the above deployment scheme may occur as a result of instrument availability or changing requirements.

Table 2-2. AVHRR instrument parameters

Parameter	Value
Calibration	Stable blackbody and space for IR channels. No inflight visible channel calibration other than space.
Cross track scan	±55.4°. from nadir
Line rate	360 lines per minute
Optical field of view	1.3 milliradians
Ground resolution (IFOV)[1]	1.1 km @ nadir
Infrared channel NEΔT[2]	<0.12 K at 300 K
Visible channel S/N[3]	3:1 @ 0.5% albedo

1) Instantaneous field of view
2) NEΔT - Noise equivalent differential temperature
3) Signal-to-noise ratio

2.2.1 High Resolution Infrared Radiation Sounder (HIRS/2)

The HIRS/2 is an adaptation of the HIRS/1 instrument flown on the Nimbus-6 satellite. The instrument, built by the Aerospace/Optical Division of the International Telephone and Telegraph Corporation, Fort Wayne, Indiana, measures incident radiation in 19 regions of the IR spectrum and one region of the visible spectrum.

Table 2-3 is a listing of the HIRS/2 parameters.

Table 2-3. HIRS/2 instrument parameters

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	±49.5° (±1125 km) @ nadir
Scan time	6.4 seconds per line
Number of steps	56
Optical field of view	1.25°
Step angle	1.8°
Step time	100 milliseconds
Ground resolution (IFOV)* (nadir)	17.4 km diameter
Ground resolution (IFOV) (end of scan)	58.5 km cross-track by 29.9 km along track
Distance between IFOV's	42 km along-track @ nadir
Data rate	2880 bits/second

*Instantaneous field of view.

Table 2-4 is a listing of the HIRS/2 spectral characteristics and noise equivalent differential radiance (NE∆N's). Note: There will be some variation in the achieved parameters from one HIRS/2 instrument to another, particularly in the NE∆N's.

2.2.2 The Stratospheric Sounding Unit (SSU)

The SSU, which has been provided by the United Kingdom, employs a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel are determined by the pressure in a carbon dioxide gas cell in the optical path. The pressure of carbon dioxide in the cells determines the height of the weighting function peaks in the atmosphere. SSU characteristics are shown in tables 2-5 and 2-6.

Table 2-4. HIRS/2 spectral characteristics

Channel	Channel frequency (cm^{-1})	μm	Half power bandwidth (cm^{-1})	Maximum scene temperature (K)	Specified NEΔN FM 3-7
1	669	14.95	3	280	3.00
2	680	14.71	10	265	0.67
3	690	14.49	12	240	0.50
4	703	14.22	16	250	0.31
5	716	13.97	16	265	0.21
6	733	13.64	16	280	0.24
7	749	13.35	16	290	0.20
8	900	11.11	35	330	0.10
9	1,030	9.71	25	270	0.15
10	1,225	8.16	60	290	0.16
11	1,365	7.33	40	275	0.20
12	1,488	6.72	80	260	0.19
13	2,190	4.57	23	300	0.006
14	2,210	4.52	23	290	0.003
15	2,240	4.46	23	280	0.004
16	2,270	4.40	23	260	0.002
17	2,360	4.24	23	280	0.002
18	2,515	4.00	35	340	0.002
19	2,660	3.76	100	340	0.001
20	14,500	0.69	1000	100% A	0.10% A

NEΔN in mW/(sr m^2 cm^{-1})

Table 2-5. SSU channel characteristics

Channel number	Central wave no. (cm^{-1})	Cell pressure (mb)	Pressure of weighting function peak (mbar)	NEΔT mW/(sr m^2 cm^{-1})
1	668	100	15	0.35
2	668	35	5	0.70
3	668	10	1.5	1.75

Table 2-6. SSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background
Cross-track scan	±40° (±737 km)
Scan time	32 seconds
Number of steps	8
Step angle	10°
Step time	4 seconds
Ground resolution (IFOV) (at nadir)	147 km diameter
Ground resolution (IFOV) (at scan end)	244 km cross-track by 186 along-track
Distance between IFOV's	210 km along-track @ nadir
Data rate	480 bps

2.2.3 The Microwave Sounding Unit (MSU)

The MSU is a four-channel Dicke radiometer making passive measurements in the 5.5-mm oxygen band with characteristics as shown in tables 2-7 and 2-8.

Table 2-7. MSU channel characteristics

Parameter	Value
Channel frequencies	50.3, 53.74, 54.96, 57.95 GHz
Channel bandwidths	200 MHz
NEΔT	0.3 K

Table 2-8. MSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background each scan cycle
Cross-track scan angle	±47.35°
Scan time	25.6 seconds
Number of steps	11
Step angle	9.47°
Step time	1.84 seconds
Angular resolution	7.5° (3 dB)
Data rate	320 bps

2.3 Data Collection and Location System (DCLS)

The Data Collection and Location System (DCLS) for the TIROS-N/NOSS series was designed, built, and furnished by the Centre National D'Etudes Spatiales (CNES) of France, who refer to it as the ARGOS Data Collection and Location System. The ARGOS provides a means for locating the position of fixed or moving platforms and for obtaining environmental data from them (e.g., temperature, pressure, altitude, etc.). Location information may be computed by differential Doppler techniques using data obtained from the measurement of platform carrier frequency received on the satellite. When several measurements are received during a given contact with a platform, location can be determined. The environmental data messages sent by the platform will vary in length depending on the

type of platform and its purpose. A technical discussion of the DCLS and the processing of its data is not included in this publication. Detailed information concerning the DCLS, including technical requirements for platforms and criteria for use of the system can be obtained by writing to:

Service ARGOS
Centre Spatial De Toulouse
18, Avenue Edouard Belin
31055 Toulouse Cedex
France

2.4 Space Environment Monitor (SEM)

The SEM instrument consists of three independent components designed and built by the Ford Aerospace and Communication Corporation. The instrument measures solar proton, alpha particle, electron flux density, energy spectrum, and the total particulate energy disposition at the altitude of the satellite.

The three components are:

a. Total energy detector (TED)

b. Medium energy proton and electron detector (MEPED)

c. High energy proton and alpha detector (HEPAD).

This instrument is a follow-on to the solar proton monitor (SPM) flown on the ITOS series of NOAA satellites. The new instrument modifies the SPM capabilities and adds the monitoring of high energy protons and alpha flux. The package also includes a monitor of total energy deposition into the upper atmosphere. The instrument augments the measurements being made by NOAA's Geostationary Operational Environmental Satellite (GOES).

A technical discussion of the SEM and the processing of its data is not included in this publication. Information can be obtained by contacting:

U. S. Department of Commerce
National Oceanic & Atmospheric Administration
Environmental Research Laboratory
Space Environmental Laboratory
Boulder, Colorado 80303

3. REAL-TIME DATA TRANSMISSION SERVICE

As mentioned previously, three separate real-time data services are available from the TIROS-N/NOAA series satellites. The data flow for these services, on board the spacecraft, is shown in figure 3-1; their characteristics are described in table 3-1.

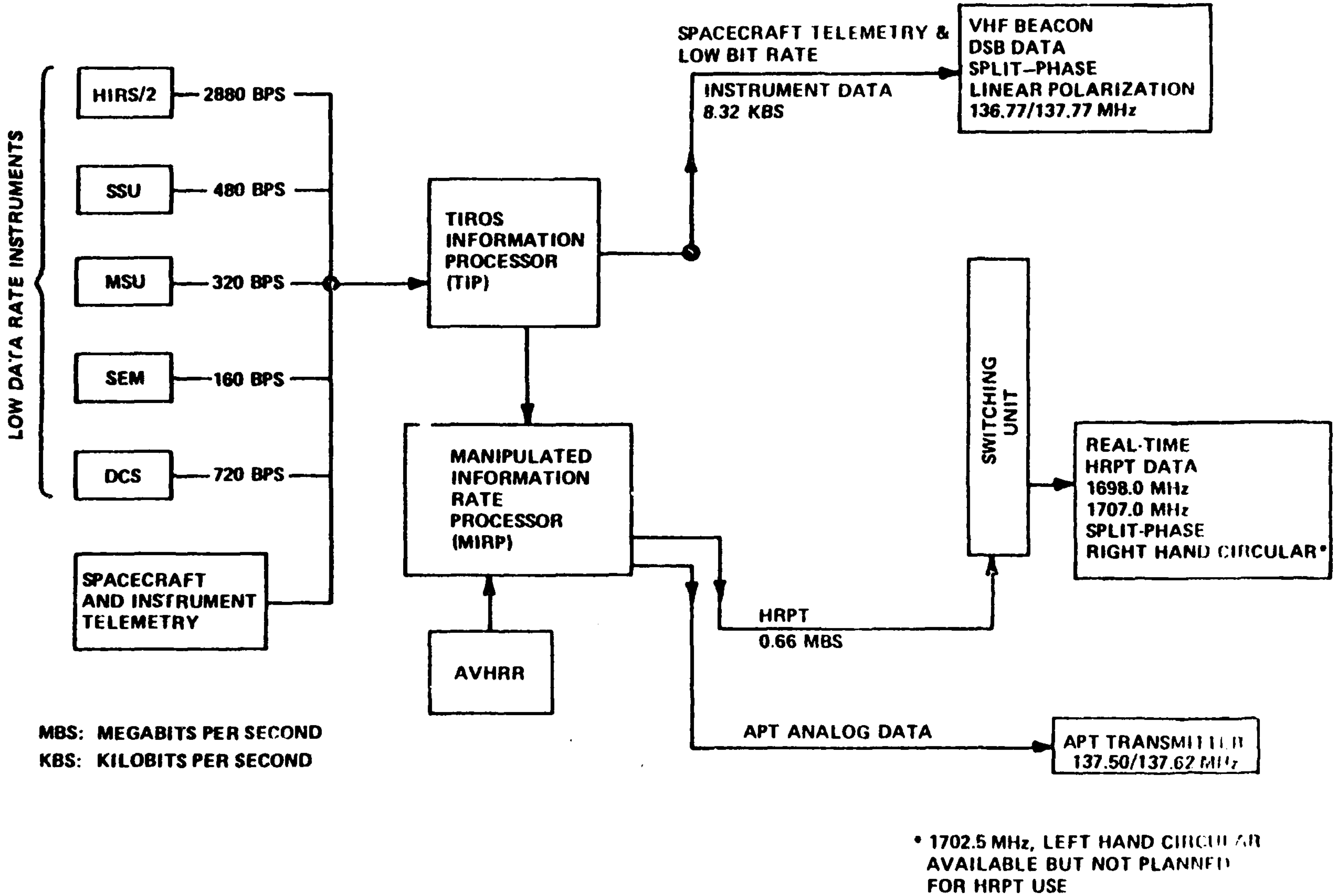


Figure 3-1. TIROS-N/NOAA real-time systems data flow

Table 3-1. Real-time data transmission characteristics

System	Characteristics
APT	VHF, AM/FM 2.4-kHz subcarrier
HRPT	S-band, digital, split phase 0.66 Mbps
DSB (includes low-bit-rate instruments such as TOVS)	VHF, digital, split phase 8.32 kbps

3.1 APT Transmission Characteristics

Video data for transmission on the APT link (output at the rate of 120 lines per minute) are derived from the AVHRR high resolution data.

The digital outputs of two selected AVHRR channels are processed in the manipulated information rate processor (MIRP) to reduce the ground resolution (from 1.1 km to 4 km) and produce a linearized scan so that the resolution across the scan is essentially uniform. After digital processing, the data are time multiplexed along with appropriate calibration and telemetry data. The processor then converts the multiplexed data to an analog signal, low-pass filters the output, and modulates a 2400-Hz subcarrier. The maximum subcarrier modulation is defined as the amplitude of gray scale wedge number eight (see figure 3-3), producing a modulation index of 87 ± 5 percent.

Tables 3-2 through 3-4 and figures 3-2 through 3-4 identify the pertinent APT characteristics.

3.2 HRPT Transmission Characteristics

All spacecraft instrument data are included in the HRPT transmission.

Output from the low data rate system, TIROS information processor (TIP) on board the spacecraft is multiplexed with the AVHRR data and becomes part of the HRPT output available to users. The low data rate system includes data from the three instruments of the TIROS operational vertical sounder (TOVS) and from the space environment monitor (SEM), the Data Collection and Location System (DCLS). and the spacecraft housekeeping telemetry.

General characteristics of the HRPT system appear in table 3-5.

Table 3-2. APT characteristics

Line rate (lines per minute)	120
Data resolution	4 km nearly uniform
Carrier modulation	Analog
Transmit frequency	137.50 MHz or 137.63 MHz
Transmit power	5 watts
Transmit antenna polarization	Right hand circular
Subcarrier frequency	2.4 kHz
Carrier deviation	±17 kHz
Ground station low pass filter	1400 Hz 7th order linear recommended
Synchronization	7 pulses at 1040 pps. 50% duty cycle for channel A; 7 pulses at 832 pps, 60% duty cycle for channel B

3.3 HRPT Format

The HRPT format provides a major frame made up of three minor frames. The AVHRR data are updated at the minor frame rate while the TIP data are updated at the major frame rate. That is, the three minor frames that make up a major frame will contain the same TIP data. The HRPT is provided in a split-phase format to the S-band transmitter. The split-phase data, (1), is defined as positive during the first half of the bit period and negative during the second half of the bit period. The split-phase data, (0). is defined as negative during the first half of the bit period and positive during the second half of the bit period. The HRPT critical parameters are given in table 3-6 and the HRPT minor frame format is shown in figure 3-5.

Specific characteristics of the HRPT transmission system are detailed in table 3-7.

Table 3-3. APT transmission parameters

Type of transmitted signal	VHF, AM/FM 2.4-kHz DSB-AM 1.44-Hz video
System output	
Frequency, polarization	137.50-MHz right circular polarization or 137.62-MHz right circular polarization
EIRP at 63° from nadir	33.5 dBm worst case 37.2 dBm nominal
Antenna	
Gain at 63° from nadir	-0.5 dBi, right circular polarization
Ellipticity	4.0 dB, maximum
Circuit losses	2.4 dB
Transmitter	
Power	5.0 watts minimum
Carrier modulation index	±17, ±0.85 kHz
Premodulation bandwidth ±0.5 dB	0.1 to 4.8 kHz
Frequency stability	$+2 \times 10^{-5}$
Subcarrier modulator	
Subcarrier frequency	2400 ±0.3 Hz
Subcarrier modulation index	87 ±5%
Post modulator filter, type 3-dB bandwidth	3-pole Butterworth 6 kHz, minimum
Premodulator filter, type 3-dB bandwidth	3-pole Butterworth-Thompson 2.4 kHz, minimum

Table 3-4. APT format parameters

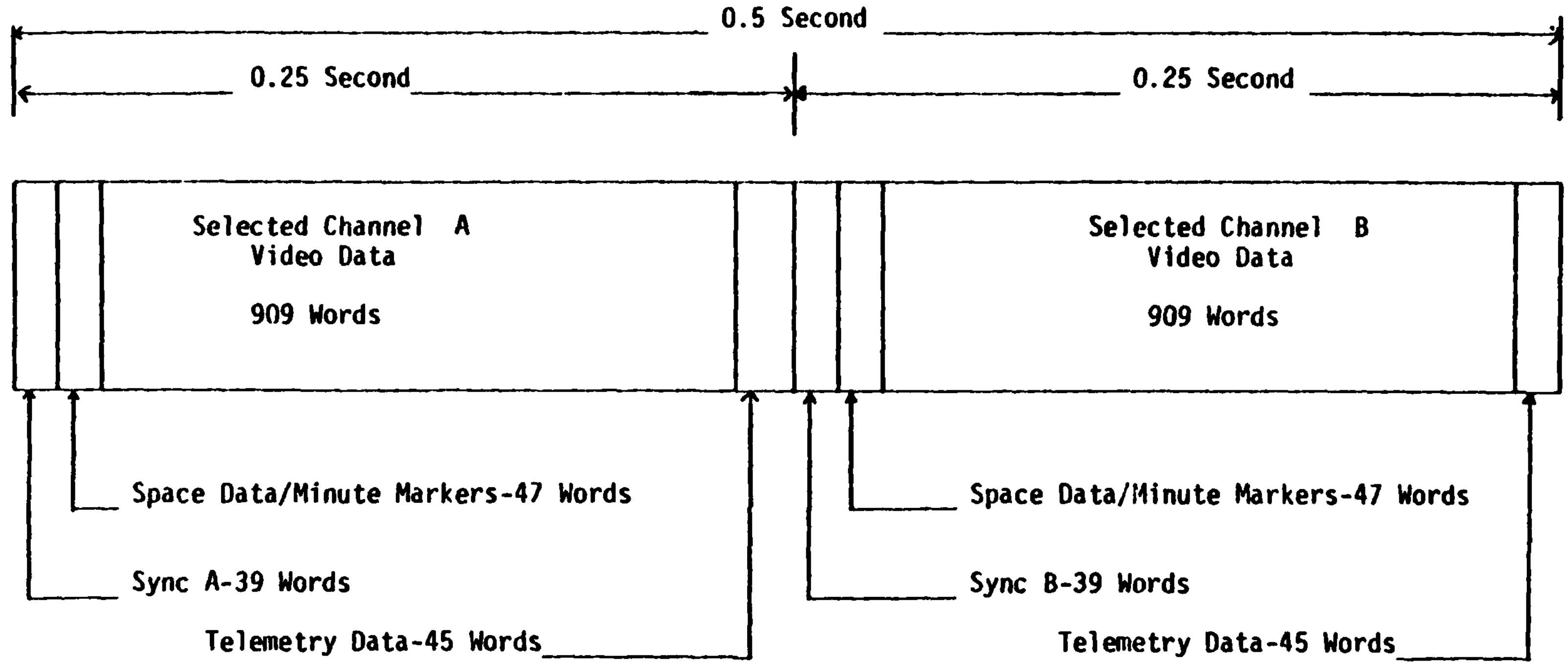
Frame	
Rate	1 frame per 64 seconds
Format	See figure 3-3
Length	128 lines
Line	
Rate	2 lines/second
Number of words	2080
Number of sensor channels	Any 2 of the 5; selected by command
Number of words/sensor chan.	909
Format	See figure 3-2
Line sync format	See figure 3-4
Word	
Rate	4160 per second
Analog-to-digital Conversion accuracy	The 8 MSB's* of each 10-bit AVHRR word
Low-Pass Filter	
Type	3rd order Butterworth-Thompson
3 dB bandwidth	2400 Hz

*Most significant bits (MSB)

Table 3-5. HRPT characteristics

Line rate	360 lines/minute
Carrier modulation	Digital split phase, phase modulated
Transmit frequency	1698.0 MHz* or 1707.0 MHz
Transmit power	5 watts
EIRP (approximate)	39.0 dBm
Polarization	Right hand circular
Spectrum bandwidth	Less than 3 MHz

*1702.5-MHz left hand circular polarization available in the event of failure of the primary frequencies.



Notes:
1. Equivalent output digital data rate is 4160 words/second
2. Video line rate - 2 lines/second
3. APT frame size - 128 lines
4. Any two of the five AVHRR channels may be selected for use
5. Sync A is a 1040-Hz square wave - 7 cycles
6. Sync B is a 832-pps pulse train - 7 pulses
7. Each of 16 telemetry points are repeated on 8 successive lines
8. Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white

Figure 3-2. APT video line format (prior to D/A converter)

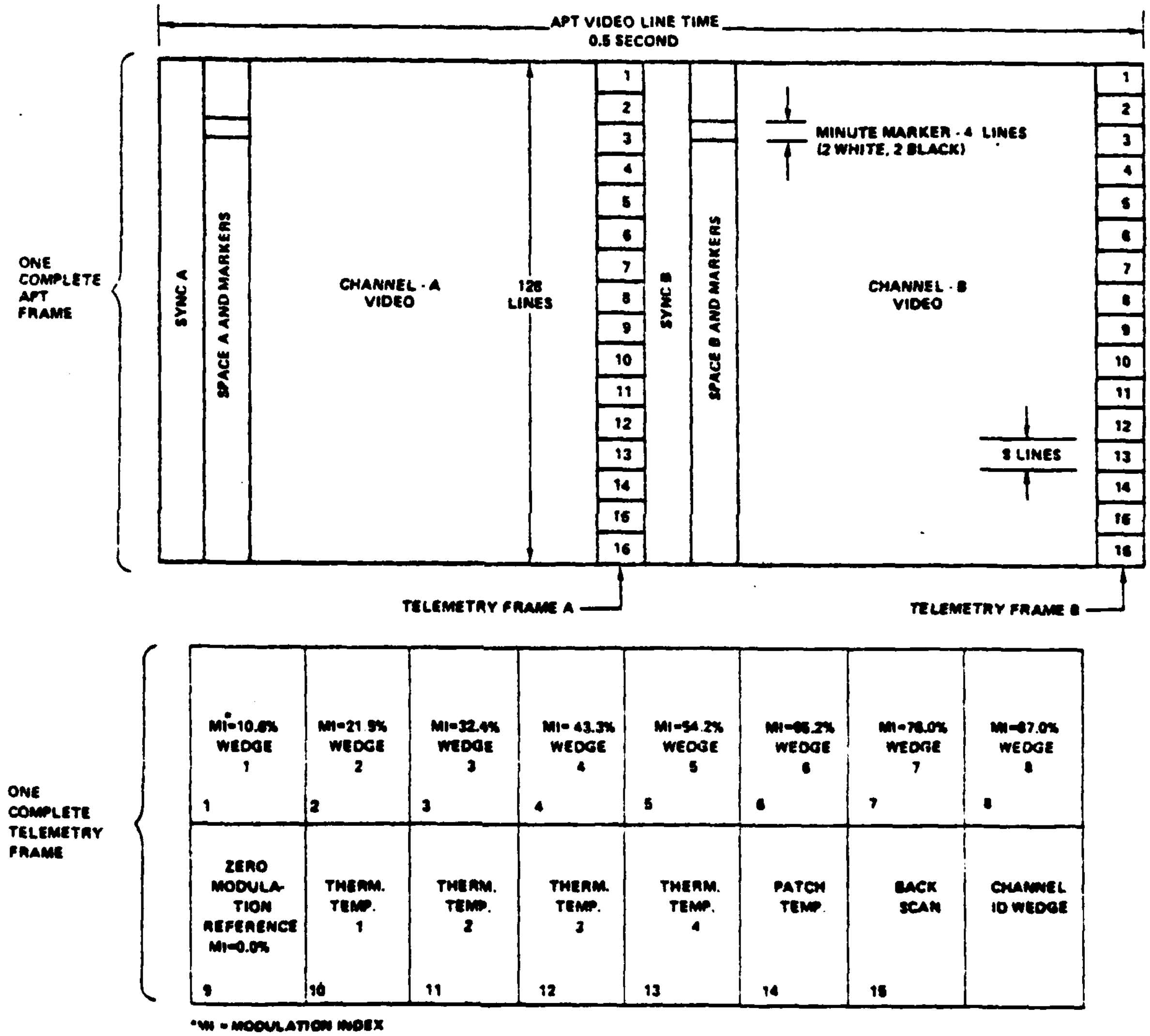
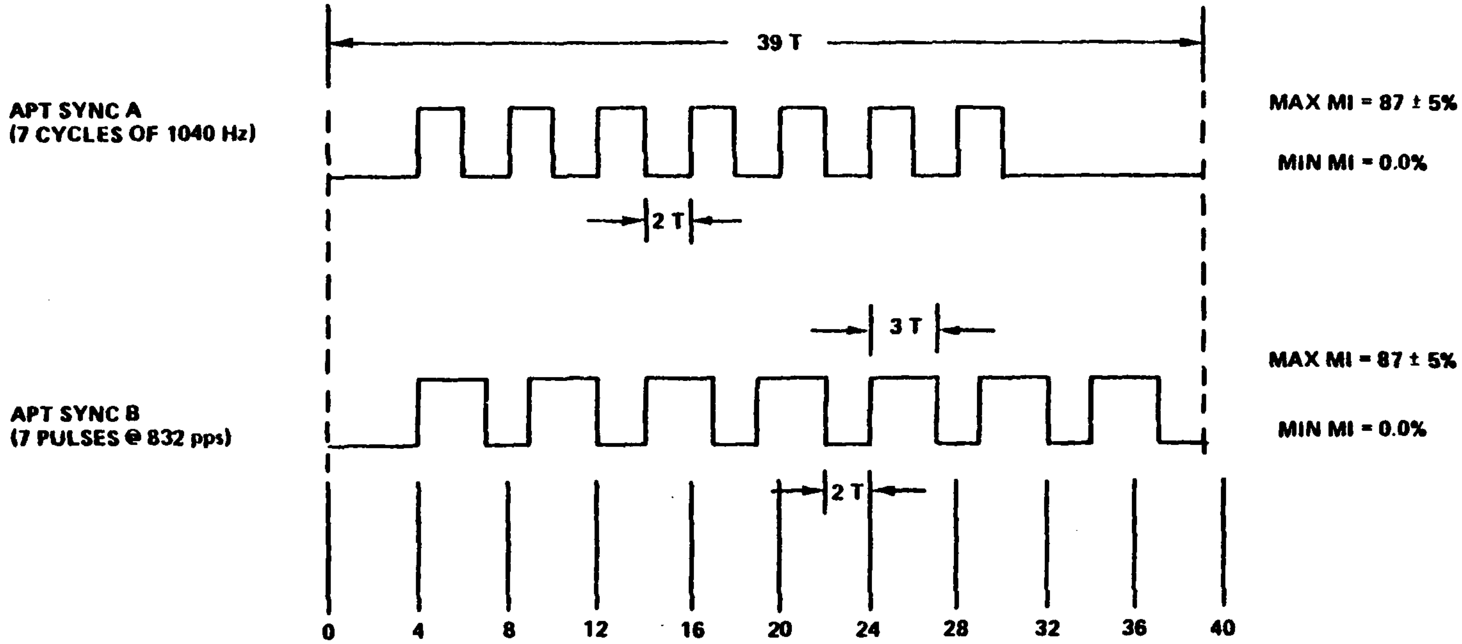


Figure 3-3. APT frame format



NOTES:

(1) $T = \frac{1}{4160} = 0.24038$ MILLISECOND

(2) SYNC A PRECEDES CHANNEL-A DATA

(3) SYNC B PRECEDES CHANNEL-B DATA

Figure 3-4. APT sync details

Table 3-6. HRPT parameters

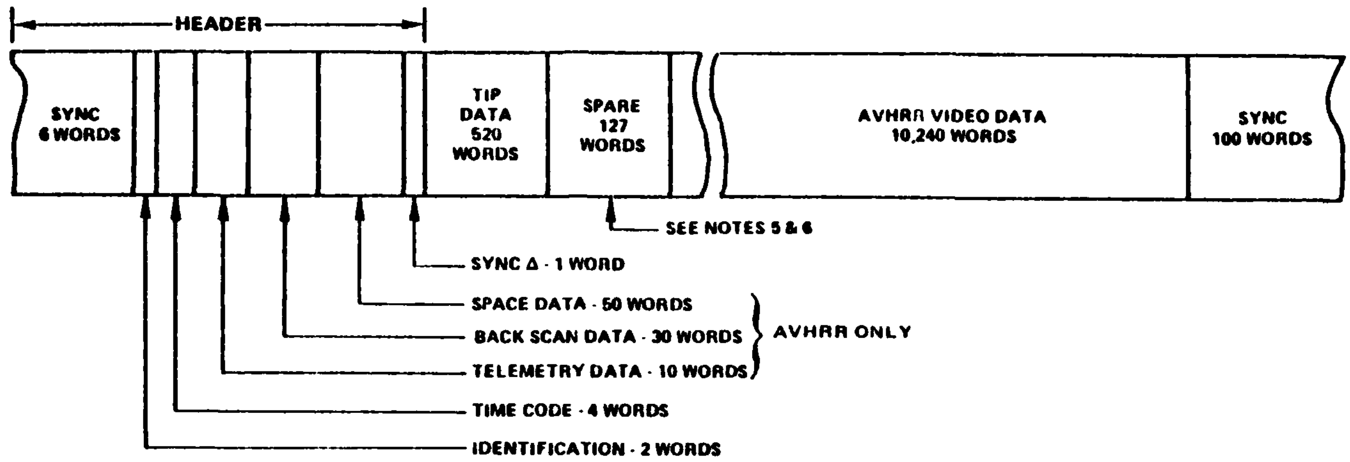
Major Frame	
Rate	2 fps
Number of minor frames	3
Minor Frame	
Rate	6 fps
Number of words	11,090
Format	See figure 3-5
Word	
Rate	66,540 words per second
Number of bits	10
Order	Bit 1 = MSB* Bit 10 = LSB** Bit 1 transmitted first
Bit	
Rate	665,400 bps
Format	Split phase
Data 1 definition	
Data 0 definition	

*MSB - Most significant bit
**LSB - Least significant bit

Table 3-7. HRPT transmission parameters

Type of transmitted signal	S-band phase modulated Split phase 665.4 kbps
System output	
Frequency & polarization	1698.0 MHz right hand circular 1707.0 MHz right hand circular 1702.5 MHz* left hand circular
EIRP at 63° from nadir	36.8 dBm worst case 40.4 dBm nominal
Antenna	
Gain at 63° from nadir	2.1 dBi, minimum
Ellipticity	4.5 dB, maximum
Transmitter	
Power out	5.25 watts minimum
Modulation index	2.35 ± 0.12 radians
Premodulation filter, type 3 dB bandwidth	5th order, 0.5°, equiripple phase 2.4 MHz
Frequency stability	$\pm 2 \times 10^{-5}$

*Not planned for HRPT use unless 1698- and 1707-MHz transmitters have failed.



NOTES:

(1) MINOR FRAME LENGTH - 11,090 WORDS
(2) THREE MINOR FRAMES PER MAJOR FRAME
(3) MINOR FRAME RATE - 6 FRAMES/SECOND
(4) WORD LENGTH - 10 BITS/WORD
(5) ALL SPARES ARE 10TH DEGREE P-N CODE (BAR).

TLM WORD ALLOCATIONS		ID WORD BIT ALLOCATIONS		
		1ST ID WORD		2ND ID WORD
1-5	RAMP CALIBRATION			(SPARE)
6	CHANNEL-3 TARGET TEMP (5 PT SUBCOM)	1	SYNC ID	
		2-3	FRAME ID	
7	CHANNEL-4 TARGET TEMP (5 PT SUBCOM)	4-7	SPACECRAFT ADDRESS	
8	CHANNEL-5 TARGET TEMP (5 PT SUBCOM)	8	RESYNC MARKER	
9	CHANNEL-3 PATCH TEMP	9	DATA 0	
10	SPARE	10	DATA 1	

Figure 3-5. TIROS-N/NOAA HRPT minor frame format

3.3.1 Detailed Description of HRPT Minor Frame Format

While figure 3-5 shows the identification and relative location of each segment of the HRPT minor frame, a detailed description of each of these segments appears in table 3-8. Bit 1 is defined as the most significant bit (MSB) and bit 10 is defined as the least significant bit (LSB).

3.4 DSB Transmission Characteristics

The TIROS-N/NOAA DSB contains the TIP output. These data are transmitted at 8.32 kbps, split phase at either 136.77 or 137.77 MHz linearly polarized. Transmission parameters are summarized in table 3-9.

The TIP output on the DSB contains a multiplex of analog housekeeping data, digital housekeeping data and low bit rate instrument data. The key parameters of the data format are contained in table 3-10. A detailed description of the TIP frame format is given in section 3.4.

3.5 TIP Data Format

The format of a TIP minor frame is shown in figure 3-6. This figure identifies the relative location of the instrument data within each TIP minor frame. A detailed description of a TIP minor frame is given in table 3-11.

Each TIP minor frame is composed of 104 eight-bit words. Bit 1 is defined as the most significant bit (MSB) and bit 8 is defined as the least significant bit (LSB). This format is retained for the DSB. When the TIP data are multiplexed into the HRPT data stream, two bits are added to each TIP word. This is described under Function, TIP data in table 3-8.

These bits are the two LSB's of each 10-bit word and, once removed, produce a TIP frame identical to that of the DSB TIP.

Each HRPT minor frame contains five unique TIP minor frames. HRPT minor frames 2 and 3 contain TIP data identical to that contained in the first HRPT minor frame. HRPT minor frames 1, 2, and 3 can be identified by examining bits 2 and 3 of data word 7 of the 103 word header, as previously defined in table 3-8. All further discussion of the TIP minor frame format will assume that the TIP data have been eliminated from 2 of the 3 HRPT minor frames and that the 2 extra bits have been removed from each 10-bit word of the remaining TIP data.

Table 3-8. HRPT minor frame format

	Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus word code & meaning
HEADER	Frame sync	6	1	1 0 1 0 0 0 0 1 0 0	First 60 bits from a 63-bit PN(1) generator started in the all 1's state. The generator polynominal is $X^6 + X^5 + X^2 + X + 1$
			2	0 1 0 1 1 0 1 1 1 1	
			3	1 1 0 1 0 1 1 1 0 0	
			4	0 1 1 0 0 1 1 1 0 1	
			5	1 0 0 0 0 0 1 1 1 1	
			6	0 0 1 0 0 1 0 1 0 1	
	ID(AVHRR)	2	7	Bit 1; 0 = internal sync; 1 = AVHRR sync Bits 2 & 3; 00 = not used; 01 = minor frame 1; 10 = minor frame 2, 11 = minor frame 3 Bits 4-7; spacecraft address; bit 4 = MSB, bit 7 = LSB Bit 8; 0 = frame stable; 1 = frame resync occurred Bits 9-10; spare; bit 9 = 0, bit 10 = 1	
			8	Spare word; bit symbols undefined	
	Time code	4	9	Bits 1-9; binary day count; bit 1 = MSB; bit 9 = LSB Bit 10; 0; spare	
			10	Bits 1-3; all 0's; spare 1, 0, 1 Bits 4-10; part of binary msec of day count; bit 4 = MSB of msec count	
			11	Bit 1-10; part of binary msec of day count;	
			12	Bit 1-10; remainder of binary msec of day count; bit 10 = LSB of msec count	
	Telemetry (AVHRR)	10	13	Ramp calibration AVHRR channel 1	
			14	Ramp calibration AVHRR channel 2	
			15	Ramp calibration AVHRR channel 3	
			16	Ramp calibration AVHRR channel 4	

(1) PN = pseudo noise

Table 3-8 (continued)

	Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10 Plus Word Code & Meaning
HEADER	Telemetry (cont.) (AVHRR)	10	17 18 19 20 21 22	Ramp calibration AVHRR ch 5 AVHRR internal target(2) temperature data (Each of these words is a 5-ch subcom, 4 words of IR data plus a subcom referance value) AVHRR patch temperature 0 0 0 0 0 0 0 0 0 1 spare
	(AVHRR) Internal target data	30	23 → 52	10 words of internal target data from each AVHRR ch 3, 4, and 5. These data are time multiplexed as ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Space data (AVHRR)	50	53 → 102	10 words of space-scan data from each AVHRR channel 1, 2, 3, 4, and 5. These data are time multiplexed as ch 1 (word 1), ch 2 (word 1), ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 1 (word 2), ch 2 (word 2), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Sync Δ (AVHRR)	1	103	Bit 1; 0 = AVHRR sync early; 1 = AVHRR sync late Bits 2-10; 9-bit binary count of 0.9984-MHz periods; bit 2 = MSB, bit 10 = LSB

(2) As measured by a platinum resistance thermometer embedded in the housing.

Table 3-8 (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Tip data	520	104 ↓ 623	The 520 words contain five frames of TIP data (104 TIP data words/frame) Bits 1-8: exact format as generated by TIP Bit 9: even parity check over bits 1-8 Bit 10: - bit 1	
Spare words	127	624	1 0 1 0 0 0 1 1 1 0	Derived by inverting the output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10} + X^5 + X^2 + X + 1$ The generator is started in the 1's state at the beginning of word 7 of each minor frame.
		625	1 1 1 0 0 0 1 0 1 1	
		626	0 0 0 0 1 0 1 1 1 1	
		627	1 0 1 1 0 0 0 1 1 1	
		628	1 1 0 1 0 1 0 0 1 0	
		↓	↓	
		748	1 0 0 1 0 1 1 0 1 0	
		749	1 1 0 0 1 0 0 0 1 0	
		750	1 0 0 0 0 0 0 0 0 0	

Table 3-8 (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Earth data (AVHRR)	10,240	751	Ch 1 - Sample 1	Each minor frame contains the data obtained during one earth scan of the AVHRR sensor. The data from the five sensor channels of the AVHRR are time multiplexed as indicated
		752	Ch 2 - Sample 1	
		753	Ch 3 - Sample 1	
		754	Ch 4 - Sample 1	
		755	Ch 5 - Sample 1	
		756	Ch 1 - Sample 2	
		↓	↓	
		10,985	Ch 5 - Sample 2047	
		10,986	Ch 1 - Sample 2048	
		10,987	Ch 2 - Sample 2048	
		10,988	Ch 3 - Sample 2048	
		10,989	Ch 4 - Sample 2048	
		10,990	Ch 5 - Sample 2048	
Auxiliary sync	100	10,991	1 1 1 1 1 0 0 0 1 0	Derived from the noninverted output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10} + X^5 + X^2 + X + 1$ The generator is started in the all 1's state at the beginning of word 10,991
		10,992	1 1 1 1 1 1 0 0 1 1	
		10,993	0 1 1 0 1 1 0 1 0 1	
		10,994	1 0 1 0 1 1 1 1 0 1	
		↓	↓	
		11,089	0 1 1 1 1 1 0 0 0 0	
		11,090	1 1 1 1 0 0 1 1 0 0	

Table 3-9. DSB transmission parameters

Type of transmitted signal	VHF, phase modulated, split phase 8320 bits per second
System output	
Frequency	136.77 or 137.77 MHz
EIRP	+19.0 dBm worst case; +24 dBm nominal
Antenna	
Gain at 63° from nadir	-7.5 dBi, minimum[1]
Gain over 90% of sphere	- 18 dBi, minimum[1]
Polarization	Linear
Circuit Losses	3.7 dB
Transmitter	
Power	1.0 watt minimum
Modulation index	±67.5 with a 7.5° tolerance
Premodulation filter, type	7-pole linear phase filter
3-dB bandwidth	16 kHz minimum, 22 kHz maximum
Frequency stability	$+2 \times 10^{-5}$

[1]Observed by an optimum polarization diversity receiver.

Each TIP minor frame contains information identifying the major and minor frame count. The major frame counter is located in bits 4, 5, and 6 of TIP word 3 and cycles from 0 to 7. The minor frame counter is composed of 9 bits. MSB is bit 8 of word 4, and the LSB is bit 8 of word 5. The minor frame count will cycle between 0 and 319 for each major frame count.

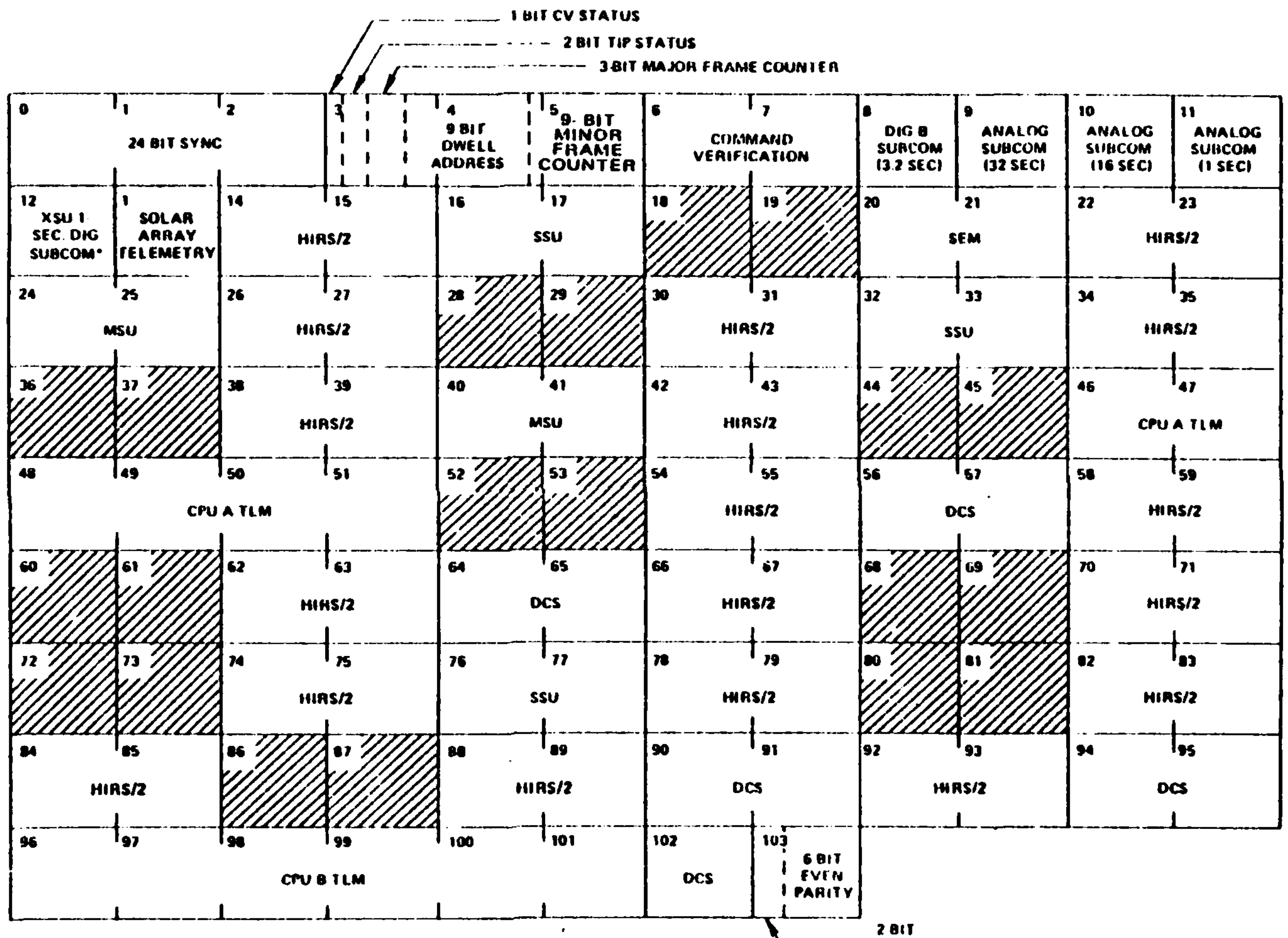
A 40-bit time code is inserted into the TIP data stream once every 32 seconds.

These bits will be located in words 8 thru 12 of each minor frame 0. The format of this time code is as follows:

9 bits day count	0 1 0 1 4 spare bits	27-bit milliseconds of day count

Table 3-10. DSB TIP parameters

Major Frame	
Rate	1 frame every 32 seconds
Number of minor frames	320 per major frame
Minor frame	
Rate	10 frames per second
Number of words	104
Format	See figure 6
Word	
Rate	1040 words per second
Number of bits	8
Order	Bit 1 = MSB Bit 8 = LSB Bit 1 transferred first
Bit	
Rate	8320 bits per second
Format	Split phase
Data 1 definition	
Data 0 definition	



NOTES: NUMBER IN UPPER LEFT HAND CORNER INDICATES MINOR FRAME WORD NUMBER
TIME CODE DATA SHALL APPEAR DURING MINOR FRAME "0" WORD LOCATIONS 8 THROUGH 12.
////// WORD LOCATIONS ARE SPARE AND CONTAIN CODE 01010101
- THE SUBCOMMUTATION FUNCTION IS ACCOMPLISHED IN THE EXTERNAL UNIT.

Figure 3-6. TIP minor frame format

Table 3-11. Detailed description of TIP minor frame

Function (no. of words)	Word position	Word format and function
Frame sync & S/C ID (3)	0 1 2	1 1 1 0 1 1 0 1 The last 4 bits of 1 1 1 0 0 0 1 0 word 2 are used for 0 0 0 0 A A A A spacecraft ID
Status (1-)	3	Bit 1: Cmd. verification (CV status: 1=CV update word present in frame: 0=no CV update in frame. Bits 2 & 3: TIP status: 00=orbital mode 10=CPU memory Dump mode 01=dwell mode 11 boost mode. Bits 4 - 6: Major frame count MSB first; Counter incremented every 320 minor frames. 000=major frame 0 111=major frame 7
Dwell mode address (1+)	3 4	Bits 7&8 Bits 1-7 9-bit dwell mode address of analog channel that is being monitored continuously. MSB is first 0 0 0 0 0 0 0 0 0 = Analog ch 0 1 0 1 1 1 0 1 0 1 = Analog ch 383
Minor frame counter (1+)	4 5	Bit 8 0 0 0 0 0 0 0 0 0 = Minor frame 0 Bits 1-8 1 0 0 1 1 1 1 1 1 = Minor frame 319.MSB is first.
Command verification (2)	6 7	Bits 9 through 24 of each received command word are placed in the 16-bit slots of telemetry words 6 and 7 on a one-for-one basis.
Time code (5)	8,9 9 9,10,11,12	9 bits of binary day count. MSB first bits 2-5: 0 1 0 1, spare bits 27 bits of binary msec of day count, MSB first. Time code is inserted in word location 8-12 only in minor frame 0 of every major frame. The data inserted is referenced to the beginning of the first bit of the minor frame sync word of minor frame 0.
3.2 - Sec. digital B subcom (1)	8	A subcommutation of discrete inputs collected to form 8-bit words. 256 discrete inputs (32 words) can be accommodated. It takes 32 minor frames to sample all inputs once (sampling rate = once per 3.2 sec). A major frame contains 10 complete digital B sub-commuted frames.
32-sec analog subcom (1)	9	A subcommutation of up to 192 analog points sampled once every 32 seconds plus 64 analog points sampled twice every 32 seconds (once every 16 seconds). Bit 1 of each word represents 2560 mv while bit 8 represents 20 mv*
16-sec analog (1)	10	These two subcoms are under Programmed. Read Only Memory control. A maximum of 128 analog points can be placed in the 169 slots. super
1-sec analog subcom (1)	11	commutation of some selected analog channels is done to fill the 169 time slots. The 170th slot is filled with data from the analog point selected by command. The slot is word number zero of the one-second subcom. The analog point may be any of the 384 analog points available. Bit 1 of each word represents 2560 mv while bit 8 represents 20 mv.

*mv: millivolts

Table 3-11 (continued)

Function (no. of words)	Word position	Word format and function
XSU digital subcom (1)	12	The cross strap unit (XSU) generates an 8-word subcom which is read out at the rate of one word per minor frame. The XSU subcom is synchronized with its word 1 in minor frame 0,8,16...
Satellite data subcom (1)	13	Solar array telemetry
Spares (20)	18,19 28,29,36 37,44,45 52,53,60 61,68,69 72,73,80 81,86,87	0 1 0 1 0 1 0 1
HIRS/2 (36)	14,15,22 23,26,27 30,31,34 35,38,39 42,43,54 55,58,59 62,63,66 67,70,71 74,75,78 79,82,83 84,85,88 89,92,93	8-bit words are formed by the HIRS/2 experiment and are read out by the telemetry system at an average rate of 360 words per second.
SSU (6)	16,17,32 33,76,77	8-bit words are formed by the SSU experiment and read out by the telemetry system at an average rate of 60 words per second.
SEM (2)	20,21	8-bit words are formed by the SEM sensor and read out by the telemetry system at an average rate of 20 words per second.
MSU (4)	24,25,40 41	8-bit words are formed by the MSU experiment and read out by the telemetry system at an average rate of 40 words per second.
DCS (9)	56,57,64 65,90,91 94,95,102	8-bit words are formed by the DCS experiment and read out by the telemetry system at an average rate of 90 words per second.
CPU A TLM (6)	46,47,48 49,50,51	A block of three 16-bit CPU words is read out by the telemetry system every minor frame.
CPU B TLM (6)	96,97,98, 99,100,101	A second block of three 16-bit CPU words is read out by the telemetry system every minor frame.
CPU data status (1-)	103	Bits 1&2: 00=All CPU data received 01=All CPU-A data received; CPU-B incomplete 10=All CPU-B data received; CPU-A incomplete 11=Both CPU-A and CPU-B incomplete
Parity (1-)	103	Bit 3: Even parity check on words 2 through through 18 Bit 4: Even parity check on words 19 through 35 Bit 5: Even parity check on words 36 through 52 Bit 6: Even parity check on words 53 through 69 Bit 7: Even parity check on words 70 through 86 Bit 8: Even parity check on words 87 through bit 7 of word 103

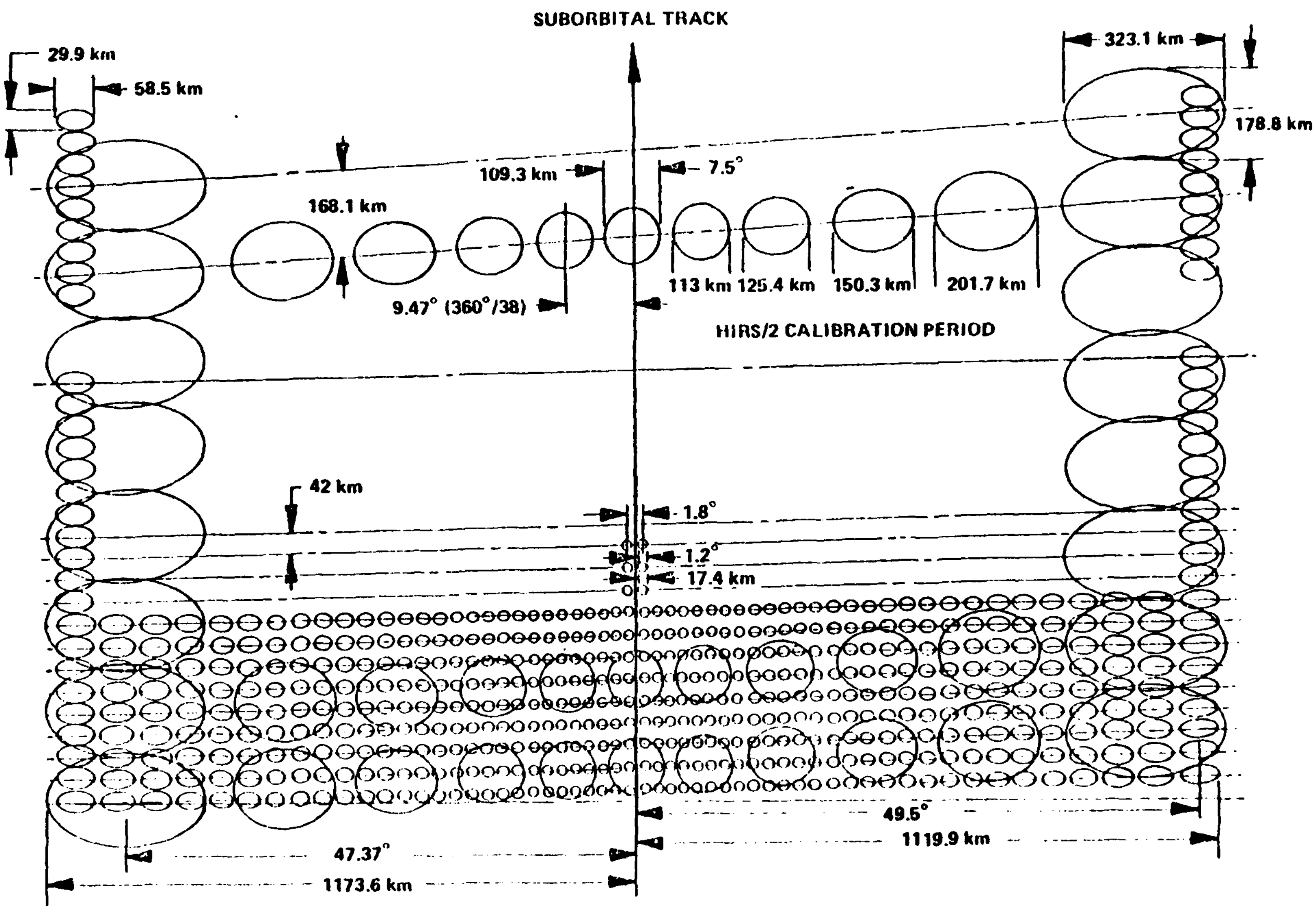


Figure 4-2. TIROS operational vertical sounder HIRS/2 and MSU scan patterns projected on Earth

APPENDIX C

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE

CONTENTS

Overview

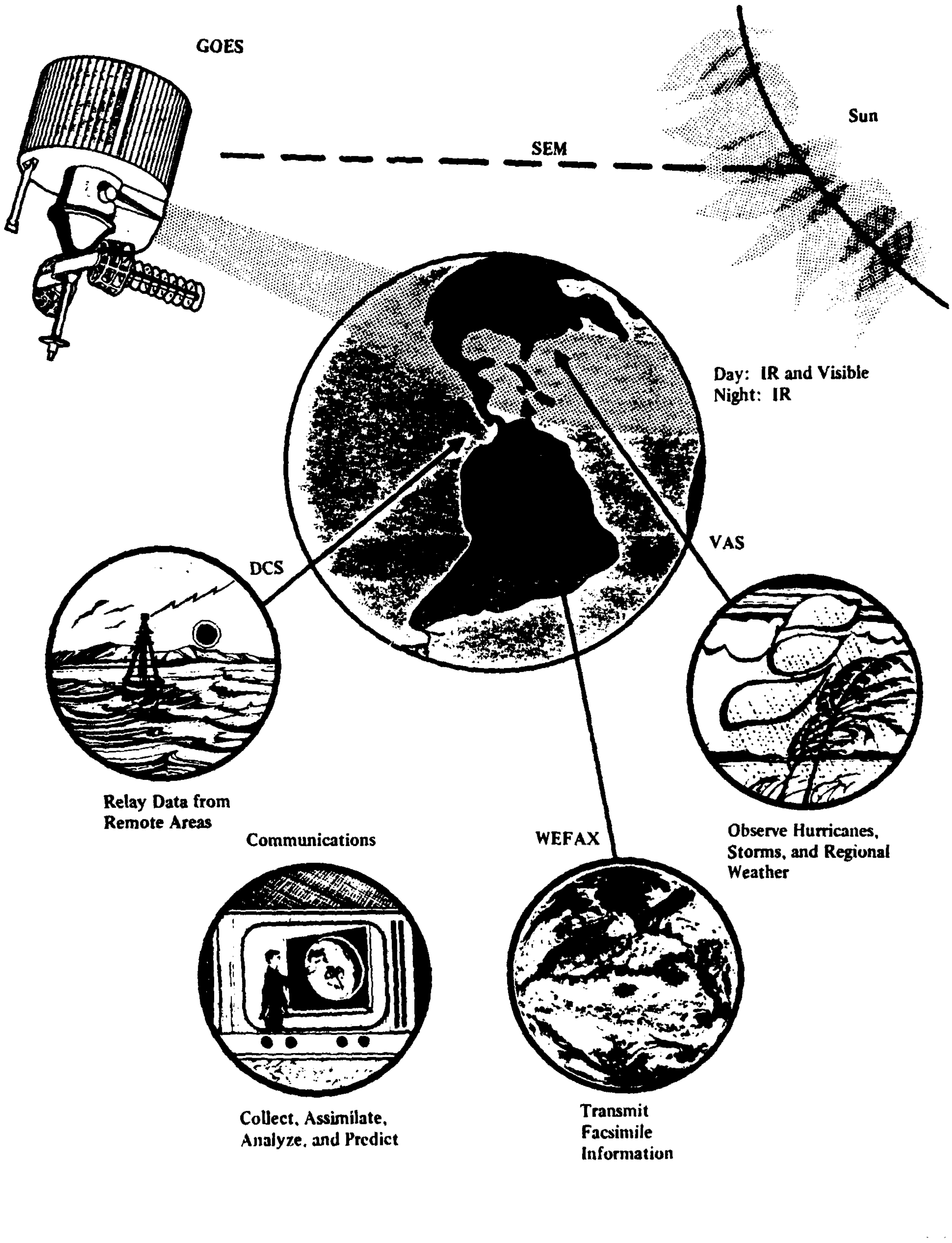
The United States developed the synchronous meteorological satellite, launching the first in 1974 and the second in 1975, for experimental operation. These SMS spacecraft were followed by the three Geostationary Operational Environmental Satellites, GOES 1, 2, and 3, launched in 1975, 1977, and 1978, respectively. The GOES D, E, and F spacecraft, now being prepared for launch, use newer technology and have expanded capability. They are expected to replace the present satellites according to a replenishment plan.

The GOES satellites make day and night observations of weather in the coverage area, monitor cataclysmic weather events such as hurricanes and other severe storms, relay meteorological observation data from surface collection points to a processing center, and perform facsimile transmission of processed graphic and imaged weather data (WEFAX) to field stations. The satellites also monitor the condition of the magnetic field and measure the energetic particle flux in the vicinity of the spacecraft, and observe X-ray emissions from the sun, transmitting these observations to a central processing point. These latter measurements are made through the instruments collectively called the Space Environment Monitor (SEM).

Day and night weather observations are made through the visible and infrared spin scan radiometer (VISSR), the principal sensor aboard the GOES 1, 2 and 3 satellites. It images the earth in the reflected visible light spectrum and in one spectral band of the terrestrial infrared (IR) thermal radiation.

Onboard the new GOES spacecraft, the weather observation sensor is a visible and infrared spin scan radiometer atmospheric sounder (VAS), which is a more sophisticated version of the VISSR. In its operational modes, the VAS scans the earth and gathers images in reflected visible light and in IR thermal radiation as did the VISSR and retains the VISSR capability as an independent operational mode. However, it can gather IR radiation in any of several spectral bands, an increased capability. Also, as it scans the earth it can produce the image in multiple IR spectral bands instead of the one band produced by the VISSR. This new experimental mode is called multispectral imaging (MSI). The VAS also has a new experimental capability, atmospheric temperature sounding, for gathering IR radiation data which can be used, with known atmospheric properties, to calculate atmospheric temperature profiles over a selected geographic area. Retained in the new spacecraft is the capability to relay data for the Data Collection System (DCS).

Exploitation of the powerful capabilities of synchronous meteorological observation satellites and their integration into the weather data collection and weather forecasting system have resulted in a sophisticated complex of mission support facilities and activities. This document presents a summary description of the total GOES system.


GOES
SEM
Sun
Day: IR and Visible
Night: IR
VAS
DCS
Relay Data from
Remote Areas
Communications
WEFAX
Observe Hurricanes,
Storms, and Regional
Weather
Collect, Assimilate,
Analyze, and Predict
Transmit
Facsimile
Information

Mission

GOES supports a service oriented operational environmental mission. The mission is to make, continuously, measurements of the earth's atmosphere and surface, determine the solar X-ray and the near-earth space environment, collect in situ data from instruments located on or near the earth's surface, and disseminate both data and analyzed environmental information to operational users. The data and information dissemination process is performed in real time and near real time, to accommodate a daily, but varying, range of operational deadlines imposed by the users whose operations depend on the timely arrival of the data.

An important, but secondary, aspect of the GOES mission is to provide data that are used by research-oriented environmental scientists for developing and testing new and/or enhanced applications. In some cases the data are used experimentally to test, develop, or validate theories.

The accompanying world map shows the geographical location of the suborbital point (the point on earth's surface directly under the satellite) of GOES East and GOES West. Both spacecraft are in an equatorial orbit which establishes their position overhead on the equator. The GOES East orbit is arranged to keep the satellite stationary over 75°W longitude; the GOES West station is over 135°W longitude. Observation accuracy of cloud phenomena declines due to geometric distortions as the position of the observed phenomenon moves away from the suborbital point. Lines on the illustration labeled "useful cloud information" represent circles about the suborbital point of approximately 60°, beyond which interpretations of cloud data are unreliable.

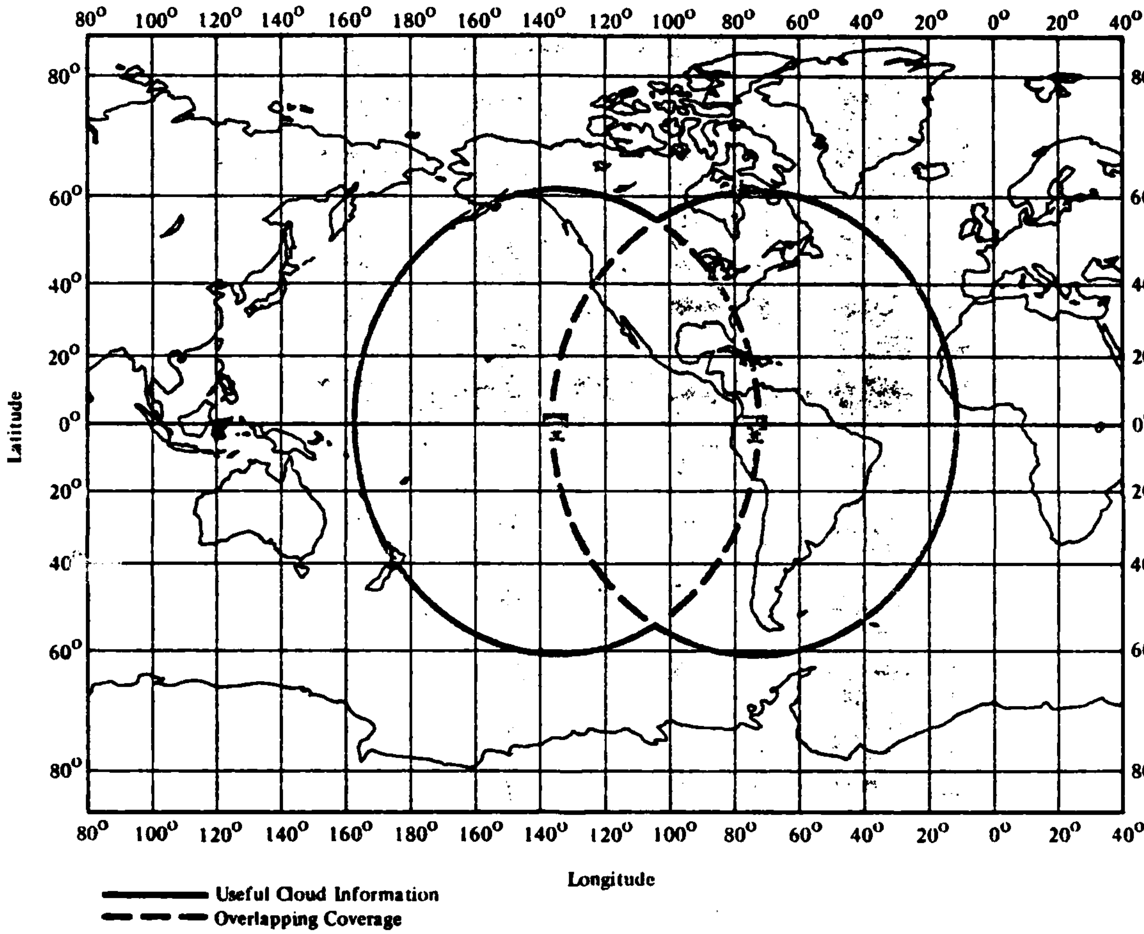
The United States is a member of the World Meteorological Organization, cooperating with that organization in the World Weather Watch. Other members have orbited, or intend to orbit, synchronous satellites with capabilities similar to GOES. Certain standardized interfaces between these satellites and their support systems allow cooperative exchanges of data.

GOES MISSION

- **Continuous day and night monitoring of atmosphere**
- **Measurements of space and solar activity**
- **Collection of in situ data**
- **Real time and near real time distribution of measurements**
- **Dissemination of products and information**

GOES SYSTEM

- **Two geosynchronous satellite platforms**
- **Spaceborne instruments for remote sensing**
  - **VAS: Earth surface and atmosphere**
  - **SEM: Space and solar activity**
- **Data Collection System (DCS)**
  - **Interrogates data from user-owned platforms**
  - **Collects users' data**
  - **Returns platform data to users**
- **Centralized preprocessing of elements common to operational users**
  - **Data formats and annotative information**
  - **Earth location and latitude/longitude gridding**
  - **Calibration**
  - **Sectoring data for user's area of geographic interest**
- **Data distribution facilities**
  - **Full resolution remote measurements through on-line space links (stretch data)**
  - **Imagery through space and ground links**
  - **Products through space links (WEFAX)**
- **Specialized application processing**



AREA COVERAGE OF GOES SATELLITES

Operational Concept

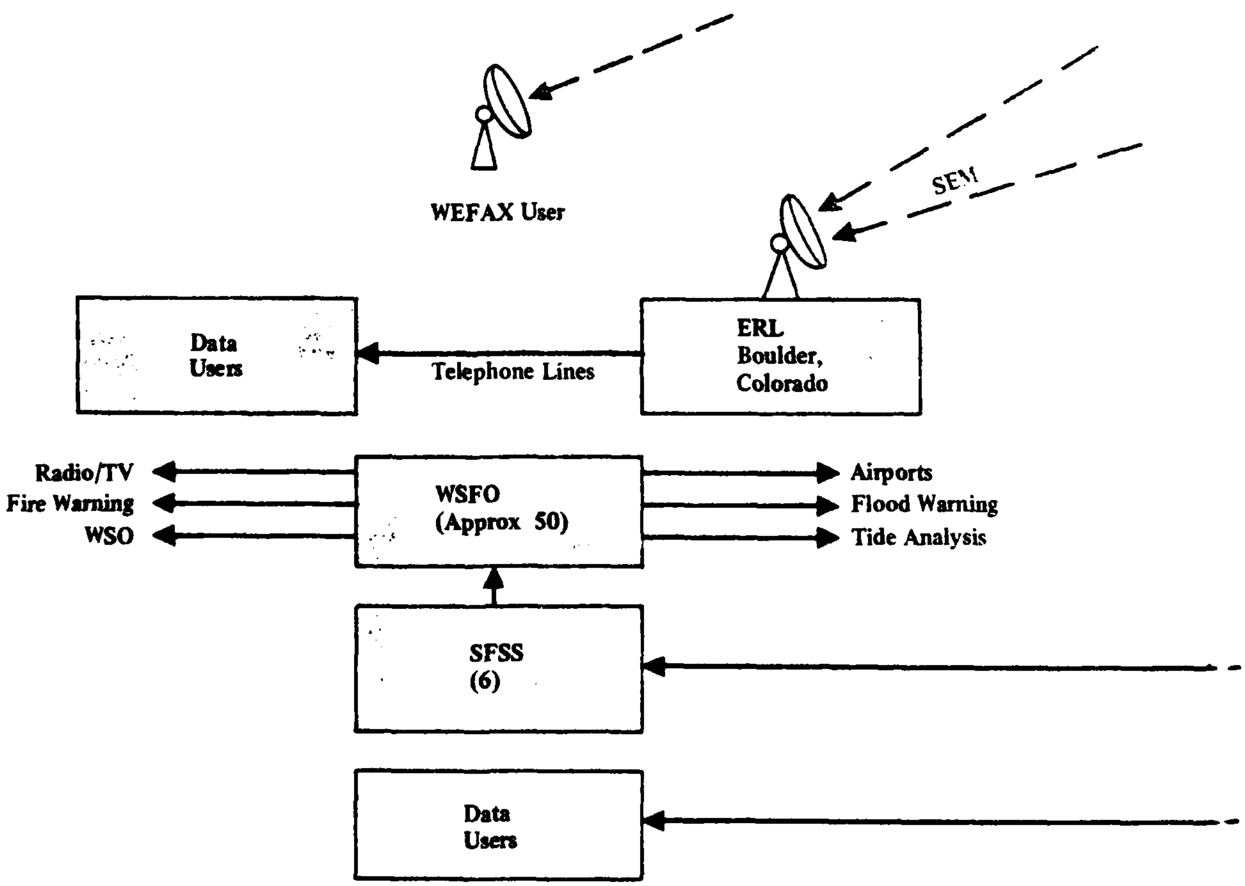
Remotely sensed measurements made by the VAS and the Space Environment Monitor (SEM) are transmitted at high data rates to the National Oceanic and Atmospheric Administration (NOAA) central Command and Data Acquisition (CDA) station at Wallops Island, Virginia. SEM data are acquired simultaneously by the Environmental Research Laboratory (ERL) at Boulder, Colorado. VISSR mode, visible, and IR data of the full earth disk are reformatted, calibrated, and gridded at the CDA station and immediately retransmitted to the GOES satellites at reduced data rates. These retransmitted data, called "stretch VISSR," are available to any user with an appropriate ground terminal.

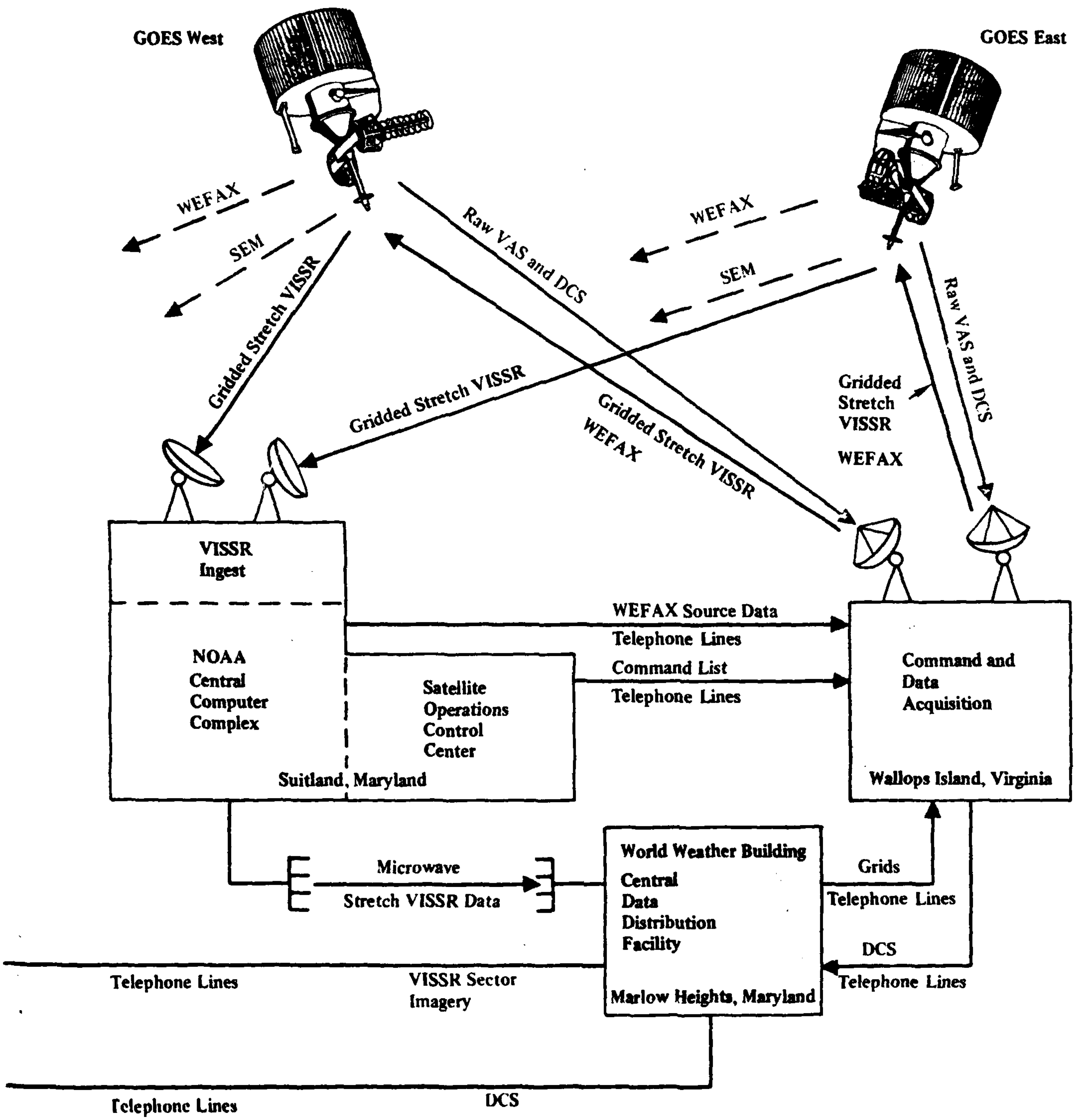
Operationally, the stretch VISSR mode signal is acquired by the National Environmental Satellite Service (NESS) at the Suitland, Maryland facility. As the digital data are recorded for subsequent application processing they are also retransmitted over a microwave link to the Central Data Distribution Facility (CDDF) in the World Weather Building in Marlow Heights, Maryland.

The CDDF divides the full earth disk digital data into smaller geographic sectors, converts the data from digital to analog, and transmits the sectored data to Satellite Field Service Stations (SFSS) located within the respective regions. National Weather Service (NWS) field offices, radio and television stations, and industrial users located within each region serviced by the SFSS can obtain pictorial imagery from a ground communications network.

Remotely located data collection platforms (DCPs) transmit data to GOES using the DCS, and the data are acquired centrally at the CDA station. These data are immediately forwarded to the CDDF where they are placed on land lines, which return the data to the users' processing locations.

WEFAX, environmental graphic products prepared by NOAA, are transmitted by land line from Suitland to the CDA station. These data are transmitted to GOES, which broadcasts them to users with direct readout terminals.




GOES West
GOES East
WEFAX
SEM
Gridded Stretch VISSR
Raw VAS and DCS
WEFAX
SEM
Raw VAS and DCS
Gridded Stretch VISSR
Gridded Stretch VISSR
WEFAX
Gridded
Stretch
VISSR
WEFAX
VISSR
Ingest
NOAA
Central
Computer
Complex
Satellite
Operations
Control
Center
Suitland, Maryland
WEFAX Source Data
Telephone Lines
Command List
Telephone Lines
Command and
Data
Acquisition
Wallops Island, Virginia
Microwave
Stretch VISSR Data
World Weather Building
Central
Data
Distribution
Facility
Marlow Heights, Maryland
Grids
Telephone Lines
DCS
Telephone Lines
Telephone Lines
VISSR Sector
Imagery
Telephone Lines
DCS

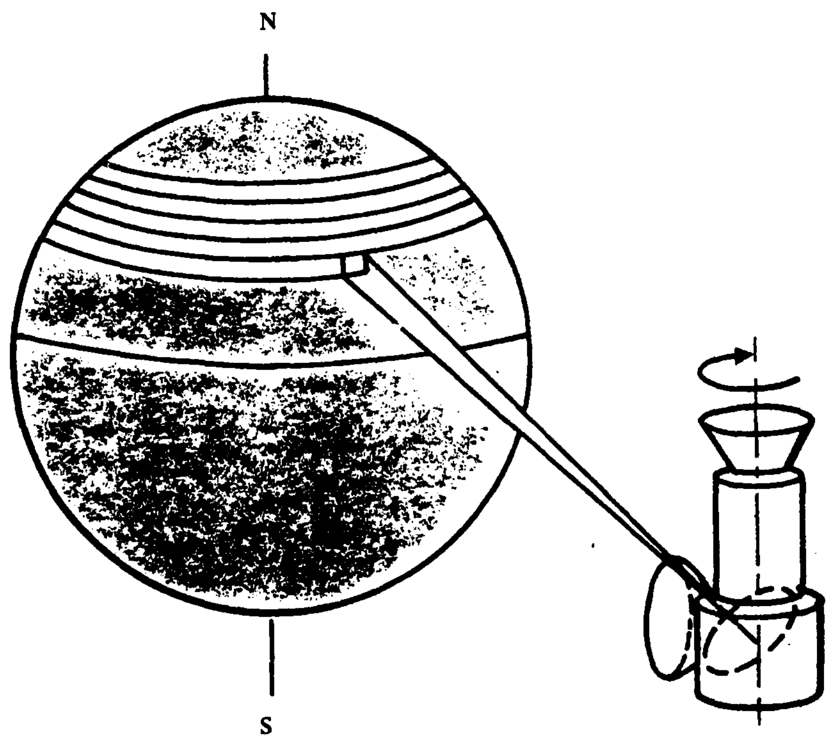
Coverage

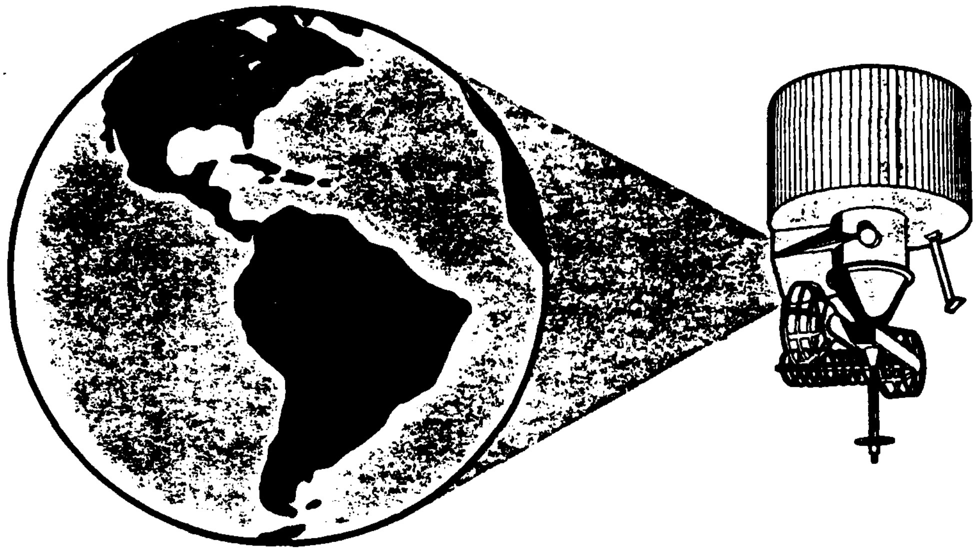
The GOES satellites are maintained at synchronous altitude, 19,312 n.mi. above the earth's surface. GOES East is located over the equator at 75°W longitude. GOES West is located at 135°W longitude. The satellites have identical capability.

The field of coverage for the operational sensing mode is 20°E-W by 20°N-S in which the full earth disk, as seen from synchronous altitude, is centered. It takes about 20 minutes to image the field. Two full earth disk images are provided each hour. The VAS instrument is programmed to start a new image at 30 minute intervals – on the hour and the half-hour. The remaining 10 minute intervals between images are used for WEFAX transmissions or ranging.

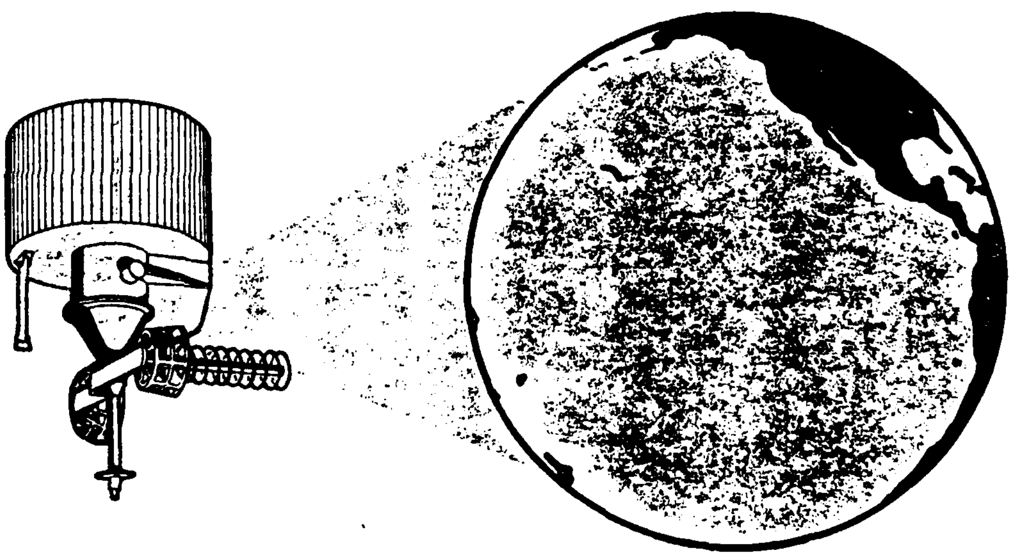
Communication paths between each GOES and the earth are line of sight. Both satellites are within line of sight of the Wallops Island CDA station, which commands and receives data from each GOES satellite simultaneously. Ground terminal locations within the coverage area of each GOES can receive sensory data signals and WEFAX. Ground based sensors from fixed or mobile locations, which are attached to suitable platforms in the coverage area of GOES, can transmit their data to GOES, using the DCS.

During periods set aside for obtaining special data for experimental purposes, the VAS instrument can be programmed for a limited coverage mode. Selected latitudinal bands of varying North-South dimensions can be imaged to obtain information for calculating a vertical profile of atmospheric temperature. More frequent repeat coverage of a particular area can be obtained when the VAS is programmed in this limited area coverage mode.





GOES East
Coverage



GOES West
Coverage

Spacecraft Configuration

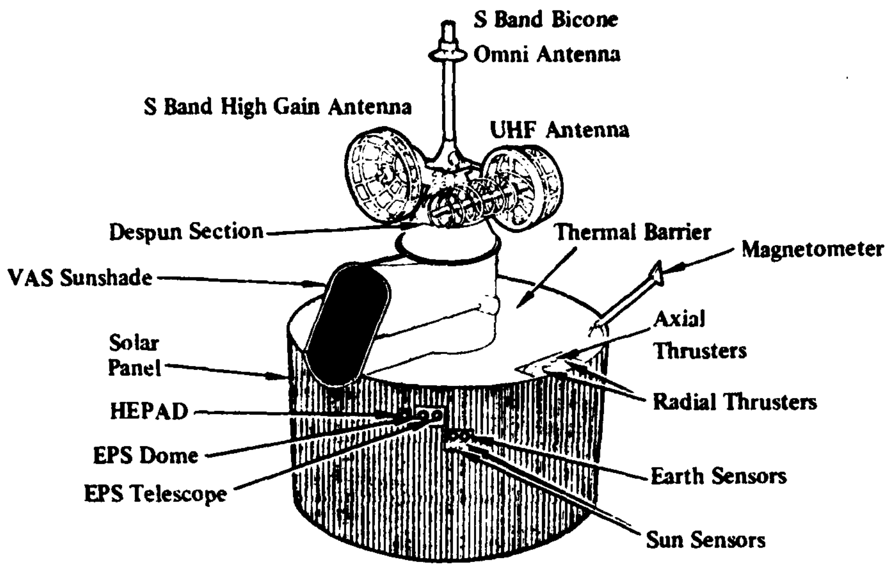
The GOES satellite consists of a spinning section and a despun, earth oriented antenna assembly. Spacecraft length, from the S band omni antenna to the apogee boost motor (ABM) nozzle aperture, is 174.3 inches. The spinning section solar panel length is 58 inches; its outside diameter is 84.5 inches. Spacecraft spin motion at a rate of 100 rpm provides a simple means for gyroscopically stabilizing attitude and controlling orientation and orbit, maintaining temperature, and generating VAS radiometric data and SEM data by spin scanning.

Despun S band and UHF antennas provide high gain for efficient communications with GOES earth stations. A low mass antenna design and compact arrangement minimize rotational and transverse inertias, and reduce to insignificant levels contributions of dynamic interaction with the rotor-mounted spin scan radiometer. Spinning sun or earth sensors supply reference signals in daylight or eclipse periods to control the despin assembly, which includes a redundant motor and precision bearings. A noncontacting RF rotary joint, mounted coaxially within the despin bearing, feeds RF signals between the despun antennas and the spinning electronics shelf.

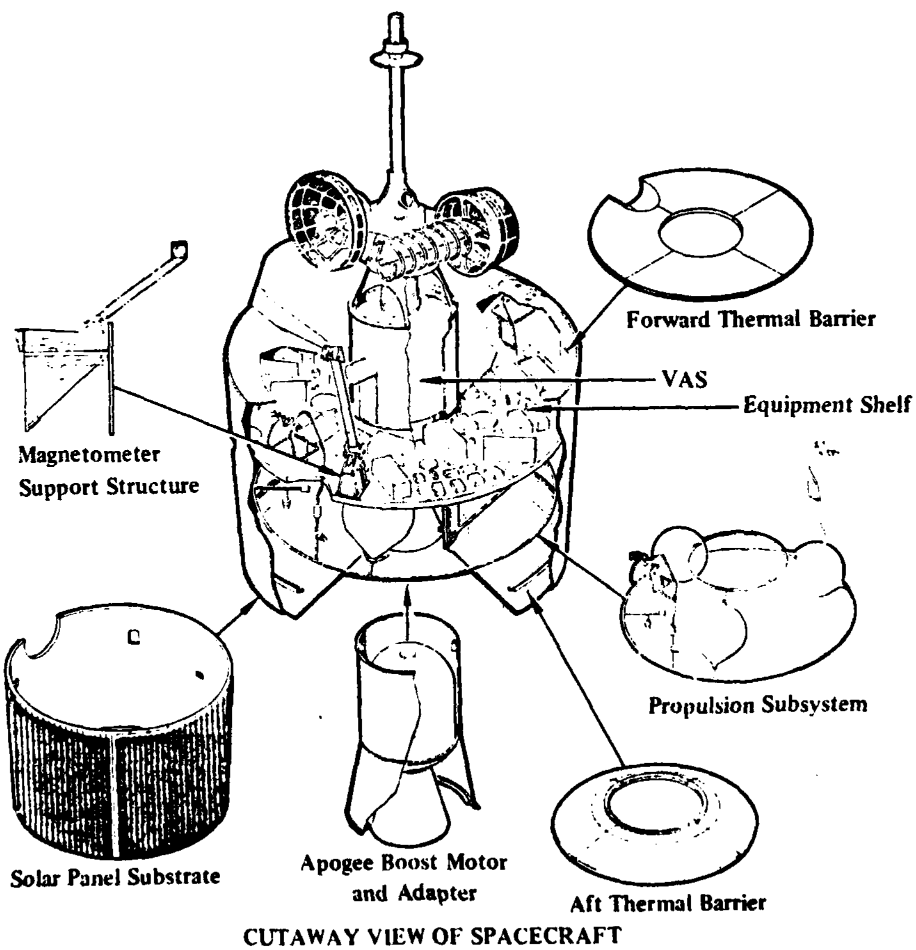
The despin bearing assembly (DBA) consists of two precision bearings, beryllium shaft and housing, redundant drive motors, and a magnetic pulse despin-to-spin angle indexer. The shaft supports the despun part of the rotary joint, and the housing carries the spun part. RF rotary joint alignment is controlled by the bearing assembly; there is no mechanical contact between spun and despun parts of the three-channel coaxial rotary joint assembly.

The spacecraft spinning section includes forward and aft assemblies. The forward assembly consists of the VAS thrust tube, equipment shelf, electronics, batteries, main wire harness, hydrazine tanks, thrusters, solar panel, and thermal barriers. Forward and aft thermal barriers combine with the solar panel to form a passive, thermally controlled envelope; heaters are included at critical points. The aft section, which includes the solid propellant apogee motor, ignition wire harness, adapter, and separation hardware, is jettisoned after apogee motor burnout.

Overall size and envelope of the GOES satellites are compatible with the Space Shuttle and Delta 3914 launch vehicles and their payload envelope constraints. Spacecraft dry weight is 762 pounds. Design life is 7 years minimum, with all subsystems providing the necessary payload support. For reliability enhancement, full redundancy is provided for all critical functions except mechanical load paths.



GOES CONFIGURATION



CUTAWAY VIEW OF SPACECRAFT

Functional Description

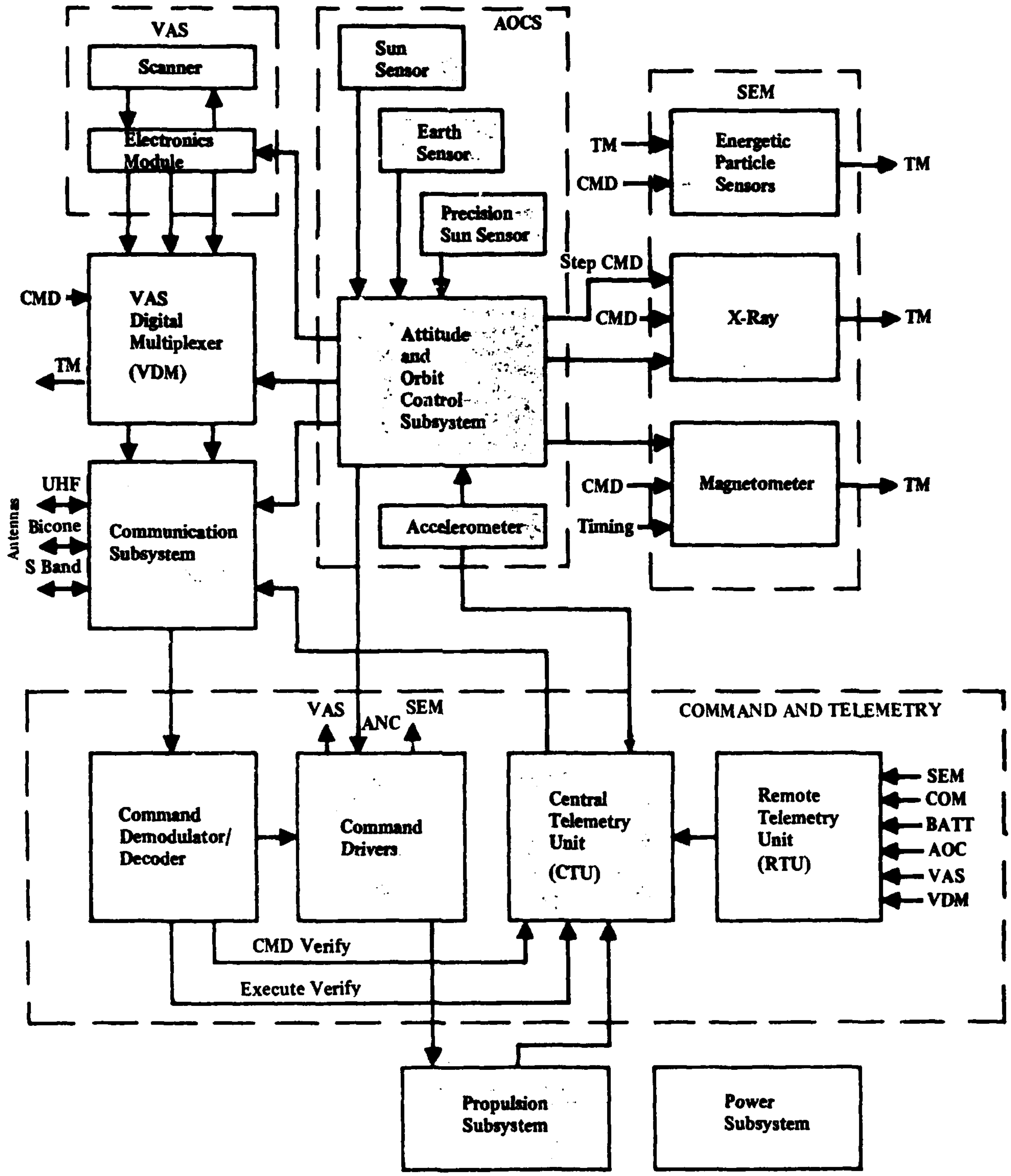
The GOES mission payload consists of the VAS, SEM, and multifunctional communications subsystem. The spacecraft and its subsystems serve to support these payloads. The output of the eight visible data channels and two IR channels on the VAS are fed to the redundant cross-strapped VAS digital multiplexer (VDM). These video channels are filtered, time-multiplexed, analog/digital (A/D) converted, and combined with VAS encoder inputs into serial data streams compatible with quadraphase modulation. The S band receiver accepts the serial data stream, modulates, and upconverts it for transmission by the S band transmitter and high gain antenna. Narrowband SEM data are multiplexed and transmitted with other telemetry data through the CDA telemetry transmitter.

Wideband data relay functions at S band (stretch VAS and WEFAX), and trilateration ranging use the multifunction repeater, which is time shared with VAS data transmissions. DCP interrogate signals, also received by the multifunction repeater through the high gain parabolic S band antenna, are processed at IF and retransmitted at UHF. DCP reports are received at UHF via the transmit/receive helix antenna and the outer channel of the tricoaxial rotary joint, then downconverted to IF, processed, and upconverted for retransmission by the dedicated DCP reply S band transmitter.

Analog data are sampled at the remote telemetry units (RTU), A/D converted, and formatted along with bilevel data into PCM 9 bit digital words. Real time analog signals are frequency multiplexed at the central telemetry units (CTU) into two real time IRIG channels. The PCM and real time telemetry multiplex transmission is via the dedicated CDA and STDN transmitters, through the center channel of the RF rotary joint, and out the omnidirectional bicone antenna. Command and ranging functions are implemented with the command/ranging transponder and the S band omni antenna. The demodulator/decoder receives the FSK/AM three tone audio format and executes commands through the driver or directly to the addressed subsystem.

The redundant despin control electronics (DCE) performs closed loop pointing control of the despun antenna array, angle reference timing for the VAS/VDM/SEM, by using the sun and earth sensor references, and automatic nutation control by using accelerometer sensors as references. The toroidal damper provides passive nutation damping of on-orbit disturbances.

Power is provided by the main solar array during periods of sunlight, and by a pair of batteries during eclipse. Loads are connected to three unregulated buses: sunlight, eclipse, and essential. The essential bus, permanently connected to the power sources, carries only the command equipment necessary to maintain a command link to the spacecraft. The sunlight bus loads are removed from the battery by the battery protection unit at the beginning of eclipse, upon sensing insufficient solar array illumination or low current. Further protection against excessive discharge is provided by detection of low battery voltage and removal of all loads except those on the essential bus. A separate 29 Vdc regulated supply connected to the sunlight bus provides for VAS loads. A solar panel-access umbilical connector is provided for ground operation.



GOES FUNCTIONAL BLOCK DIAGRAM

Operational Modes

The spacecraft and its operational modes are compatible with existing GOES ground network and mission objectives.

All telemetry, command, and ranging functions are conducted via an S band communications system which is compatible with the STDN and CDA stations. Near continuous transfer orbit coverage is provided by two STDN stations and the operations performed are similar to previous GOES launches.

Direct transmission of VAS data and spacecraft-relayed stretched VAS, WEFAX, and trilateration data are time shared in a single multifunction S band repeater.

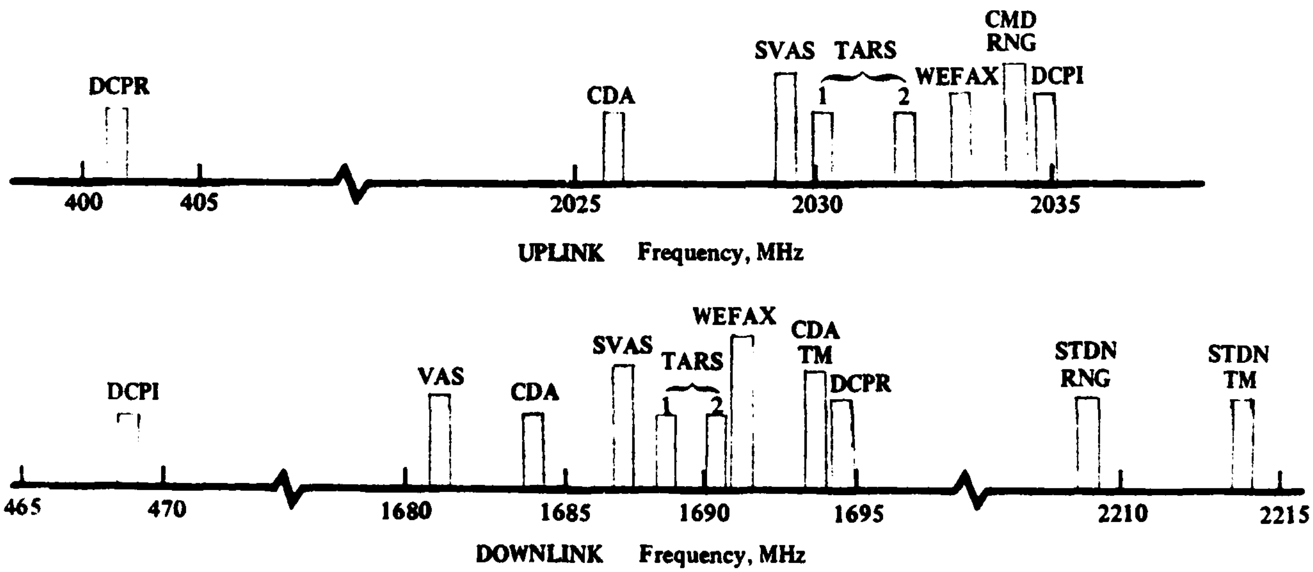
The table shows the spacecraft subsystem status during the standard operating modes. Mode M_1 (inactive standby) requires only the command receiver and demodulator/decoder to be powered; Mode M_2 adds either CDA or STDN telemetry and is suitable for in-orbit storage (active standby). The spacecraft is compatible with Mode M_1 since it can be commanded without telemetry verification. Mode M_3 requires all telemetry, command, and ranging functions in the spacecraft for normal launch and transfer orbit operations.

Sunlight Modes S_1, S_2, and S_3 provide for full operational capability. They differ only in the service provided by the multifunction repeater, i.e., VAS real time and stretch data transmission, WEFAX data, or trilateration ranging relay. The channelized S band repeater separates telemetry, STDN ranging, and DCP reports from the wider bandwidth multifunction downlink channel to avoid intermodulation. Command, telemetry, and ranging are accomplished with a separate command and ranging unit operating with a CDA or STDN telemetry transmitter through the bicone omni antenna.

The spacecraft is capable of performing the following sequence of operations every 60 minutes during sunlight periods in orbit:

MINUTES	MODE
20	S_1
10	S_2 or S_3 or alternating between
20	S_1
10	S_2 or S_3 or alternating between

Spacecraft batteries allow continuous operation in Mode E_2 during all eclipses throughout the mission.

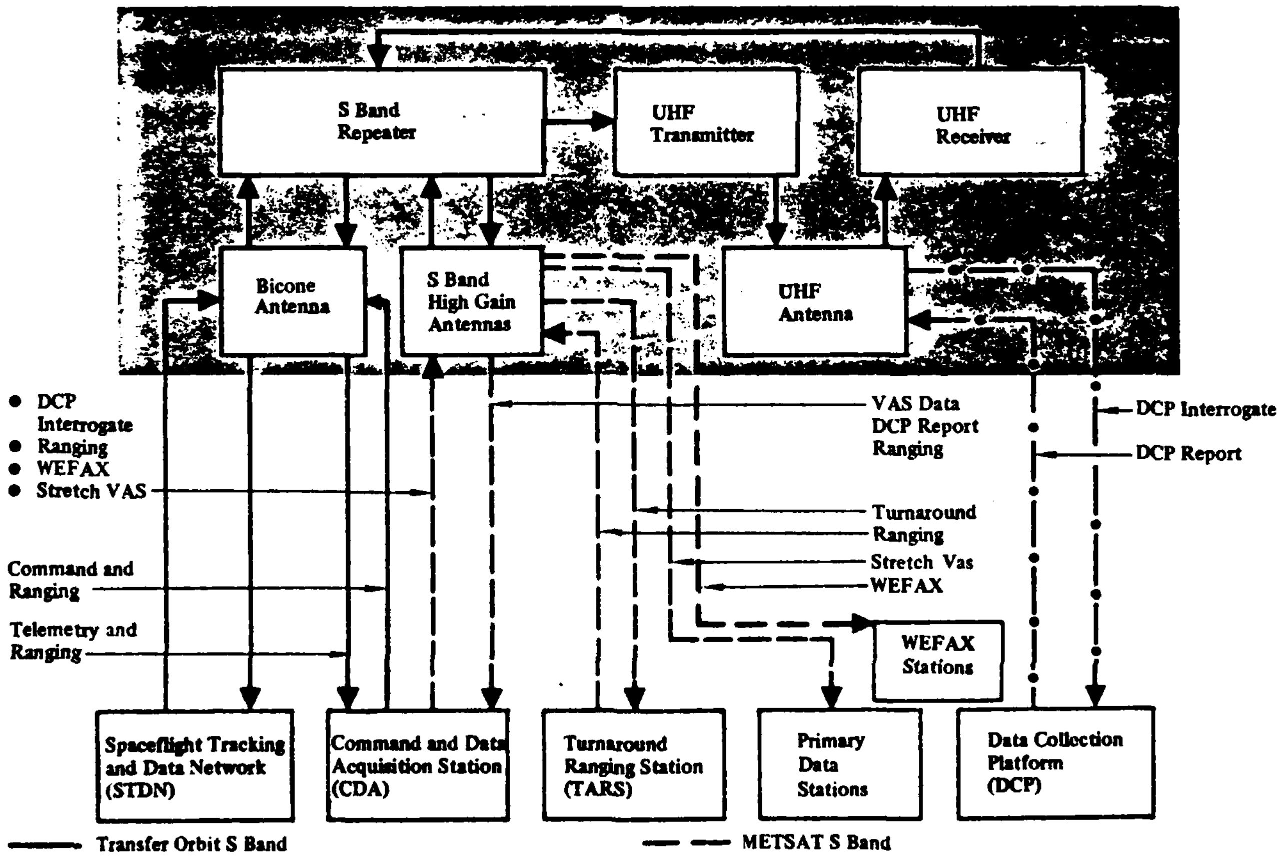


UPLINK AND DOWNLINK FREQUENCY SPECTRA

SPACECRAFT STANDARD OPERATING MODES

Function	Miscellaneous			Synchronous Orbit				
				Sunlight			Eclipse	
	M_1	M_2	M_3	S_1	S_2	S_3	E_1	E_2
Command decoder	X	X	X	X	X	X	X	X
CDA telemetry		X	X	X	X	X	X	X
STDN telemetry		X*	X					
STDN transponder								
Ranging		X	X					
Command	X	X	X	X	X	X	X	X
DCPR repeater				X	X	X	X	X
DCPI repeater			X	X	X	X	X	
Multifunction repeater								
Stretch VAS				X**				
WEFAX					X			
Trilateration						X		
VAS data transmission				X**				
VDM				X				
SEM								
EPS and HEPAD				X	X	X	X	X
X-ray				X	X	X		
Magnetometer				X	X	X	X	X

*Either CDA or STDN telemetry. **Time-shared.



GOES OPERATIONAL COMMUNICATION LINKS

Cloud and Temperature Imaging

Cloud and temperature imaging in both the visible and infrared (IR) spectra is accomplished through the VAS. By means of the VAS optical reflecting telescope, the radiation from a very small area on earth is focused on detectors which convert the radiation energy to electrical signals. The spacecraft data transmission link relays these signals to earth, where they are processed into various useful forms. The detectors are arranged in the focal plane in a predetermined pattern so that each detector defines a field of view (FOV) in the focused area. The pattern is designed to ensure imaging of the entire earth as the mission proceeds.

Imaging is achieved by scanning the optically focused spot over the earth. The radiation enters the telescope at right angles to its optical axis via the optically flat scan mirror, which is provided with an angular-positioned stepping mechanism to facilitate scanning of the terrestrial scene. The scanned pattern, as processed for use, resembles a conventional television image. West-to-East scan lines are formed by rotation of the spinning spacecraft. The lines are moved by the stepped mirror to scan North-to-South. Synchronizing signals are also sent through the spacecraft so that imaging signals will be properly assembled on receipt by the terrestrial stations.

Visible spectrum (0.55 μm to 0.75 μm) data consist of sunlight reflected from earth and its various cloud formations. The data are detected and converted to electrical signals by an array of eight photomultiplier tubes. Each tube views an eighth of the scan line width, so that eight lines are scanned on each spin of the spacecraft. These data, available only when terrestrial reflecting surfaces are in daylight, can be used to image clouds and their motion. Wind velocity can then be estimated.

Infrared (IR) spectrum data consist of emitted radiation from earth and clouds and depend only on their temperatures. The IR energy is thus available both day and night, permitting continuous IR imaging. Temperatures can be determined from the IR data. Solid-state detectors, cooled to 94°K by the radiative cooler, convert the IR energy to electrical signals.

There are two types of detector elements, sensitive to different parts of the IR spectrum. Two large and two small detectors are made of a mercury and cadmium telluride composition (HgCdTe) and are placed in the relative positions illustrated. Two other detectors made of indium selenide (InSb) are placed as illustrated. All detectors are square shaped. The large detectors are the same size. They are separated in the North-South scan direction by a space exactly equal to the dimension of a side. The small detectors are one half the size of the large detectors, exactly one scan line on a side. This arrangement of detectors facilitates the several imaging modes of VAS.

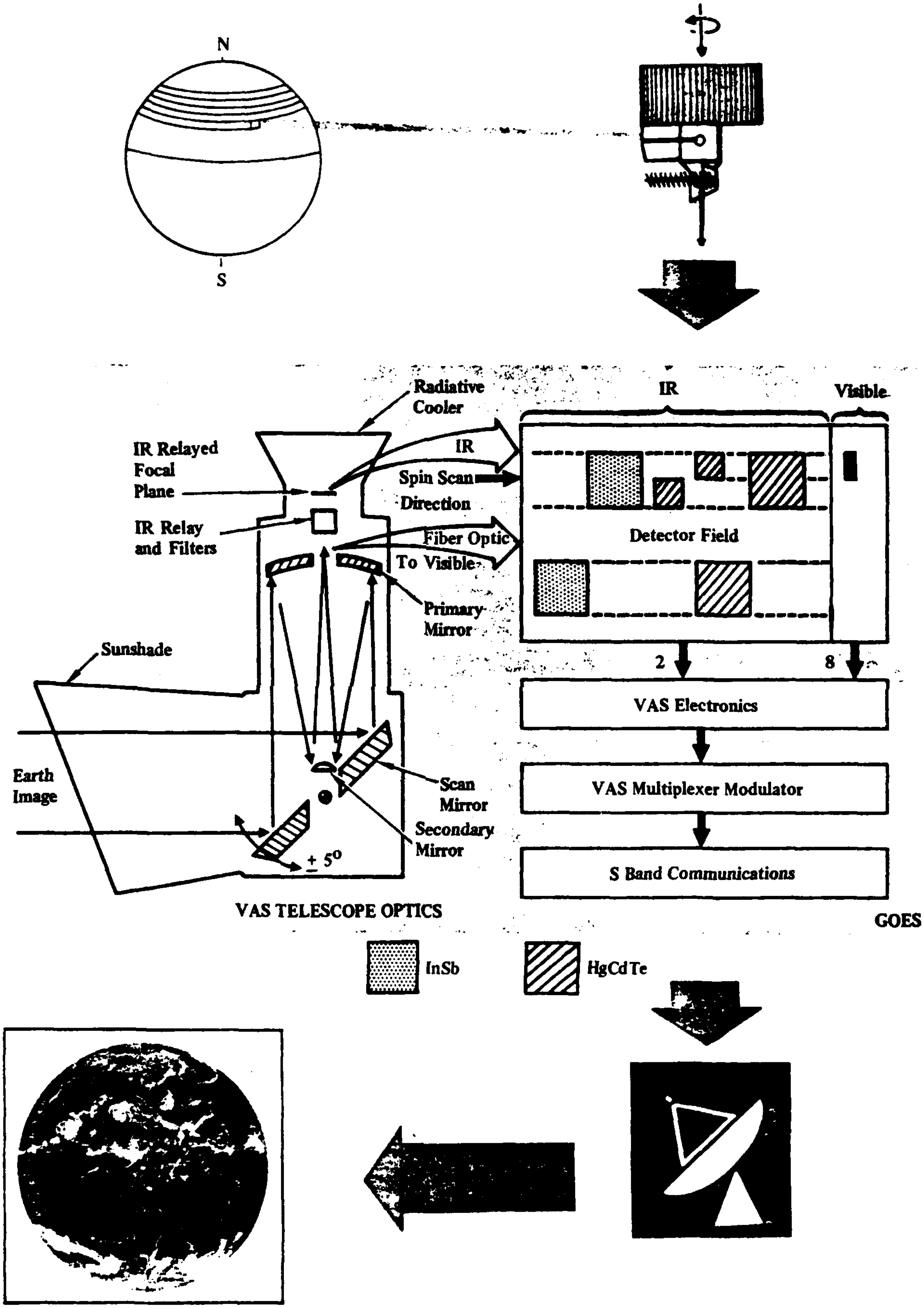
Imaging modes are determined by selection of the detector signals to be transmitted. This selection is done by an onboard programmer in the VAS; its programming logic can be rearranged at will by the terrestrial control station, which must only reload the memory of the programmer with new instructions, via the spacecraft command link. Only two detector signals can be connected simultaneously.

VISSR Mode

This mode, in which the data of the visible spectrum detectors and the small IR detectors are transmitted on every scan line, is the operational mode. The resulting images are identical to those available from prior GOES spacecraft. Filter wheel position and frame size are controlled by time-synchronized command link. The onboard programmer is inoperative.

Multispectral Scan Mode

For multispectral scan imaging, the VAS is programmed to transmit visible spectrum data on every scan line. It is programmed to transmit IR detector signals in pairs: two small HgCdTe, two large HgCdTe, or two InSb. By the selective use of filters in combination with detectors, and by interleaving the scans of large and small detectors as facilitated by the North-South spacing of the detectors, a full frame of scans can image the earth in as many as three IR spectral channels.


N
S
Radiative
Cooler
IR Relayed
Focal
Plane
IR Relay
and Filters
IR
Spin Scan
Direction
Fiber Optic
To Visible
Primary
Mirror
Sunshade
Earth
Image
Scan
Mirror
Secondary
Mirror
± 5°
VAS TELESCOPE OPTICS
IR
Visible
Detector Field
2
8
VAS Electronics
VAS Multiplexer Modulator
S Band Communications
GOES
InSb
HgCdTe

Atmospheric Sounding

The goal of this function is to measure terrestrial temperature brightness in certain IR spectral bands, permitting calculation of a profile of atmospheric temperature as a function of atmospheric pressure-altitude, and detecting the relative distribution of water vapor in the atmosphere.

The concept of "topside atmospheric sounding" is based on the physical behavior of certain evenly distributed, absorptive atmospheric gases, e.g., carbon dioxide (CO_2). The spectral sharpness of the absorption frequencies of these gases tends to broaden, with increased pressure, from the top of the atmosphere down to the earth's surface. Thermal radiation from the earth and the atmosphere in the spectral vicinity of the absorption line, shining upward through the atmosphere, is detected by a group of narrowband detectors spectrally located along the edges of the absorption band. A set of data will be obtained which can be used, with known properties of the distributed gas, to calculate a temperature profile.

The figures illustrate the spectral location of the VAS detection bands compared to a rough representation of the transmission characteristics of the atmosphere over the spectral range of interest. There are seven detection bands in the region of CO_2 absorption and three in the regions of water vapor absorption. Two "window" bands are also provided, one spectrally nearer the long wave absorption band detectors and one near the short wave detectors.

Narrow detection bands are formed by combinations of detectors sensitive over relatively wide bands in the spectral regions of interest, and several narrowband filters which are mechanically inserted into the optical path, as needed, by a servo-positioned "filter wheel."

The temperature versus pressure-altitude profile is determined from solution of a family of equations of the following form where one such equation is formed for each sounding detection band:

$$T_B(\nu) = \int_{P_{surface}}^{0} W(p, \nu)\, T(P)\, dp$$

P,p	represent atmospheric pressure (pressure-altitude)
ν	represents infrared radiation frequency
$T_B(\nu)$	represents the radiation brightness measured by VAS in a particular spectral band
$W(p,\nu)$	is a weighting function which may be calculated for that spectral band from basic atmospheric data
T(P)	represents the temperature at a pressure-altitude, the parameter-pair sought from these measurements

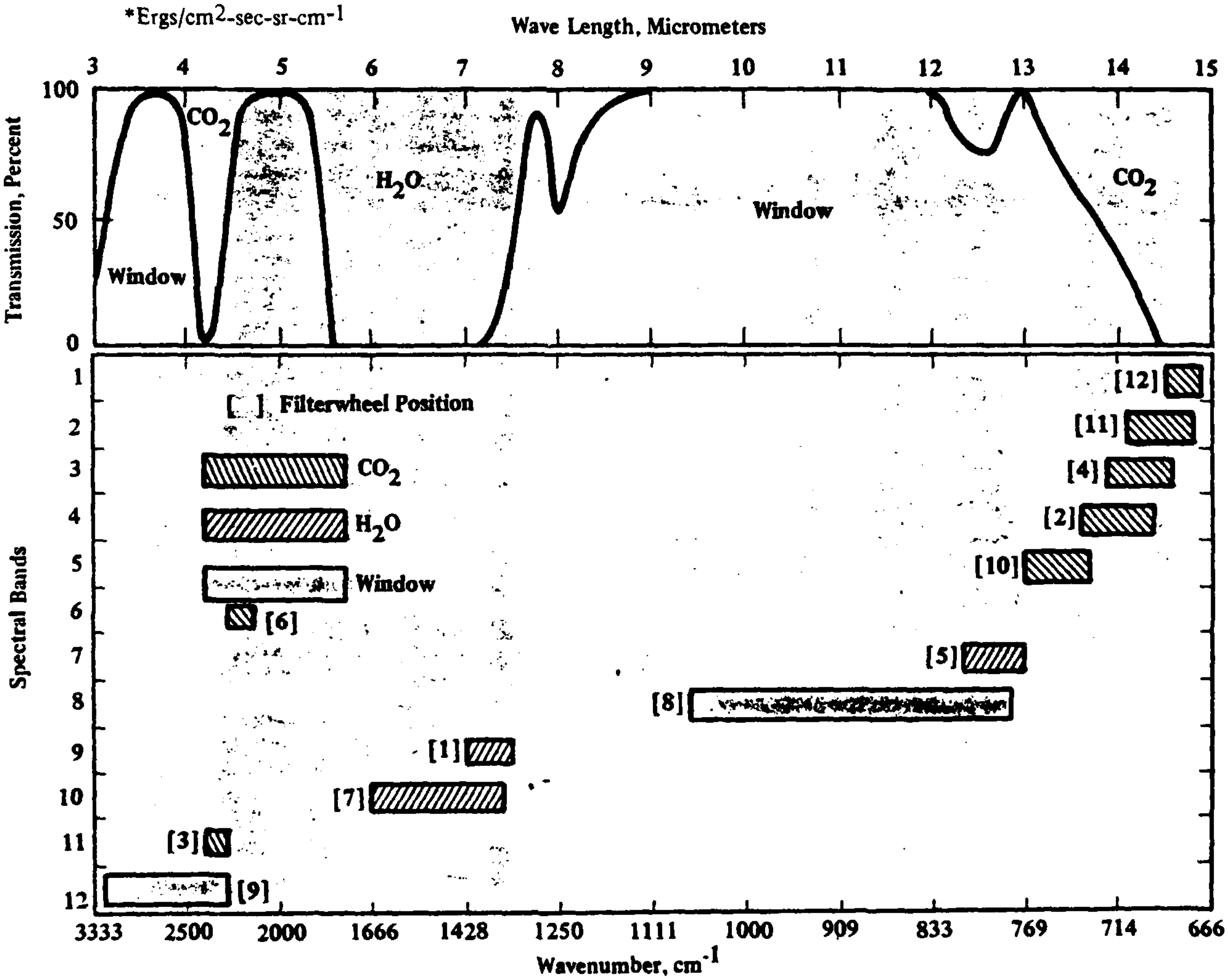
T(P) is determined by a mathematical process called inversion, which can be performed by several different algorithms. All such algorithms have a kinship to differentiation, meaning that T(P) is sensitive to noise in the measurement, $T_B(\nu)$. Signal to noise ratio (S/N) is improved in the VAS sounding mode by a correlation technique comprising multiple scanning of each scan line during data acquisition and subsequent signal integration over the multiple scans. Consequently a single line must be scanned a sufficient number of times to achieve an acceptable S/N for the calculated T(P). The total number of times a line must be scanned to cover all bands with the required scans is called the spin budget, which is about 185 for VAS. Thus, to make a whole-earth-disk frame would require about 13 hours.

Typical design and performance numbers are shown.

TYPICAL VAS INFRARED SPECTRAL BAND DATA

Spectral Band	Atmospheric Pressure, mb	λ, μm	Δν, cm⁻¹	Remarks: Band	Remarks: Detector Type	S/N Improvement Requirements: NEN/IGFOV*	S/N Improvement Requirements: Sounding NEN*	S/N Improvement Requirements: Spin Budget
1	65	14.73	10	CO_2	HgCdTe	10.390	0.25	6
2	100	14.48	16	CO_2	HgCdTe	3.490	0.25	14
3	325	14.25	16	CO_2	HgCdTe	3.000	0.25	11
4	450	14.01	20	CO_2	HgCdTe	2.200	0.25	7
5	Surface	13.33	20	CO_2	HgCdTe	2.080	0.25	7
6	700	4.525	45	CO_2	InSb	0.063	0.004	35
7	Surface	12.66	20	H_2O	HgCdTe	1.930	0.25	7
8	Surface	11.17	140	Window	HgCdTe	0.296	0.25	1
9	375	7.261	40	H_2O	HgCdTe	1.770	0.15	16
10	330	6.725	150	H_2O	HgCdTe	0.482	0.10	3
11	280	4.444	40	CO_2	InSb	0.073	0.004	46
12	Surface	3.945	140	Window	InSb	0.022	0.004	4

*Ergs/cm^2-sec-sr-cm^{-1}



VAS IR SPECTRAL BANDS

VAS Characteristics

The VAS is designed to operate in a spinning spacecraft of modest weight which can be orbited by Delta class boosters. The cylindrical shape permits the VAS to fit inside the thrust tube of a classically designed spinning spacecraft structure, thereby minimizing the effects on spacecraft weight, balance, and moment of inertia. Design requirements on imaging capability dictate a telescope of relatively large optics. To avoid the great weight of large precision optics made from conventional material such as glass mirrors mounted in steel structures, the entire VAS structure and principal optics are made of beryllium, a very light, stiff metal with the required dimensional stability.

When the VAS is installed in the spacecraft, its optical axis becomes parallel to the spacecraft spin axis, which must be parallel to earth's axis. The VAS optical axis is thus perpendicular to the direction of the earth scene. The optically flat scan mirror of the VAS, placed at a 45° angle to the VAS optical axis, directs the earth scene into the VAS. The spinning motion of the satellite scans the earth scene West-to-East. North-to-South scanning is accomplished by stepping the scan mirror from 40°, representing the North polar extreme, to 50°, representing the South polar extreme. An angle position encoder integral with the mirror stepping mechanism converts the position information to electrical signals, which are sent to the CDA station to aid in reassembly of the earth scene. The 10° of mirror motion (resulting in 20° of optical angle due to doubling of the optical angle at the mirror) is divided into 1820 steps, each representing 192 μrad optically.

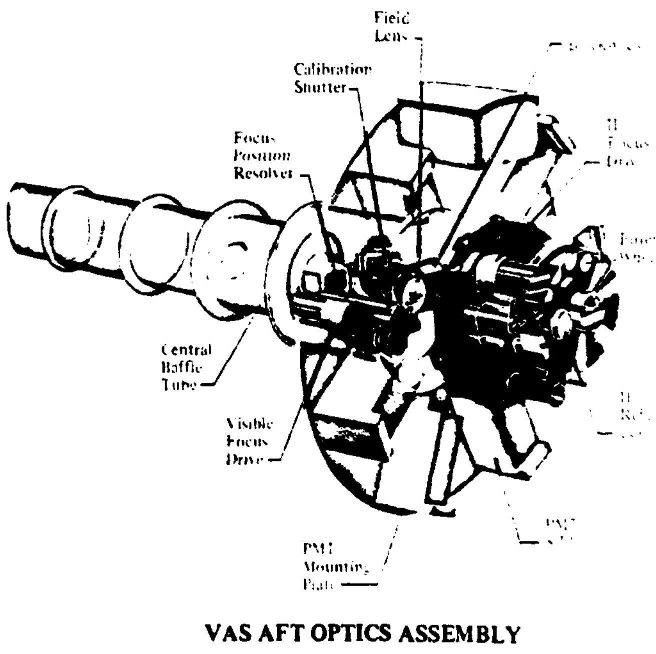
The Ritchey-Chretien optical system, which is similar to the well known Cassegrain system except for the surface contours of the mirrors, is used because it provides a larger field at the focal plane than the Cassegrain. The increased field is necessary to accommodate the numerous detector elements required for electrical conversion of the focused image.

At the image plane, a relatively large field of view (FOV) is available. Each detector element is dimensioned to define the FOV which its signal is intended to represent. For example, the smallest IR field is 192 μrad, defined by a square detector 0.00315 inch on each side. (At synchronous altitude, 192 μrad is equivalent to 5 miles along the earth's surface at the satellite's suborbital point.)

Two focal planes are used in the VAS. Visible spectrum signals are obtained at the principal focus. An optical fiber for each of the eight FOVs defines the field to be measured (25 by 24 μrad) and conveys the impinging light within that FOV to a photomultiplier tube, which converts the light intensity to a proportional electrical current.

IR radiation must be sensed by solid state detectors which are cooled to a low temperature to reduce their intrinsic electrical noise to a level below the electrical equivalent of the least intense radiation to be measured. This cooling is provided by a radiative cooler which radiates excess heat into space. Because of spacecraft design constraints, the cooler must be located away from the prime focal plane. This requirement is accommodated by relay of the IR signals to another, conveniently placed focal plane. The relay optics provide an appropriate location for an IR focusing mechanism and filter assembly out of the visible light path. Filters are inserted in the IR path only, and used in the MSI and sounding modes.

The scanning program and the various modes of operation are controlled by the electronics module, which contains appropriate supporting electrical units, including an onboard programmer which can itself be reprogrammed via the spacecraft command link.

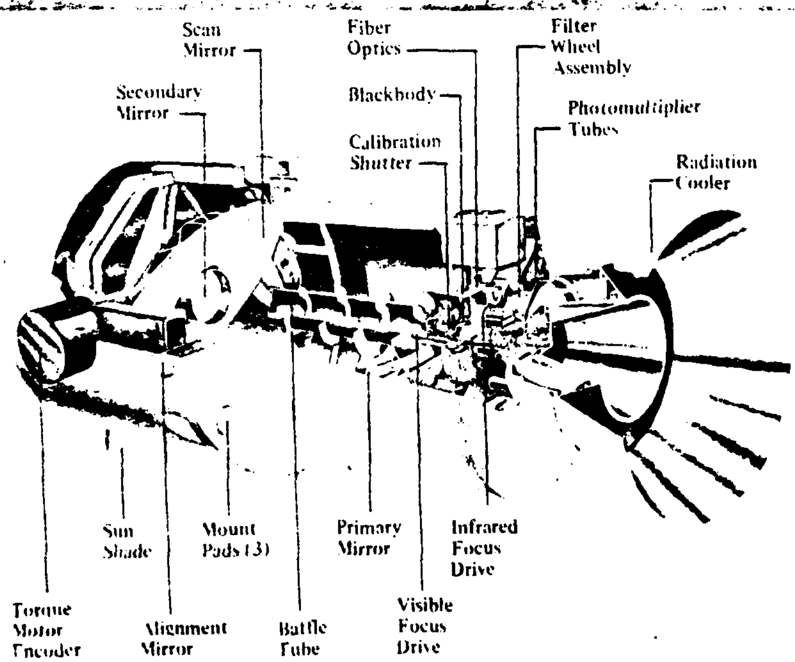


VAS AFT OPTICS ASSEMBLY

VAS CHARACTERISTICS

Size	
Length	~1.5 m
Radial dimension	~0.65 m
Weight	
Scanner	64.3 kg
Electronics module	10.5 kg
Structural material	Beryllium (structure and mirrors)
Optics	Ritchey-Chretien system 40.64 cm dia primary mirror Focal length 292.1 cm Optically flat scan mirror
Detectors	
Visible spectrum	8 photomultiplier tubes coupled to focal plane by optical fibers which define IGFOV: 21 x 25 μrad
Infrared spectrum	Solid state detectors cooled to 95°K 2 HgCdTe; IGFOV: 192 μrad 2 HgCdTe; IGFOV: 384 μrad 2 InSb; IGFOV: 384 μrad
Spectral bands	By filters inserted in IR optical path; 12 filters selectable from rotating wheel
Radiative cooler	Servoed operating temperature ~95°K Heat rejection capacity ~16 mw Minimum temperature ~82°K
In-orbit calibration	Radiometric IR: Temperature monitored blackbody cyclically reflected into optical axis Visible: Optical aperture providing sun signal of 50% earth albedo Electronic IR and Visible: Stairstep voltage into amplifier chain
Onboard programmer	Reprogrammable by command link Selects and controls scan sector size and center position Controls filter wheel and selects transmitting detector pair

VAS SCANNER CUTAWAY



Data Relay Function

Through its multifunction S band and UHF repeaters, GOES performs several relay functions.

The multifunction repeater, illustrated in the block diagram, has a common receiver for the two S band transmitters, a low power transmitter for relaying data collection platform replies (DCPR), and a high powered transmitter for other functions. Its UHF repeater allows communication between the spacecraft and the data platforms. The table, Data Relay Interfaces, presents some design features and performance information.

VAS imaging signals are transmitted to the command and data acquisition (CDA) station and stretch VISSR is relayed from the station to stretch VISSR users via the S band repeater. The terrestrial image is scanned and transmitted in a 20° interval of the spacecraft spin cycle. The stretch VISSR is relayed during the remaining 340° of spin cycle. These functions are given priority on the high powered S band transmitter during the imaging period, which consists of about 20 minutes in each half-hour.

In the remaining 10 minutes, the multifunction repeater may be scheduled to relay the "turn-around" ranging signals for the trilateration ranging system or may relay weather facsimile (WEFAX) if scheduled. WEFAX consists of graphic charts and images which are standardized in message format so that they may be recorded on standard receiving equipment by any user in the satellite coverage area.

The GOES spacecraft can also relay interrogations to, and data replies from, data collection platforms (DCP). DCPs are terrestrially located platforms -- fixed or mobile -- which sense and report conventional weather and/or environmental parameters, e.g., atmospheric temperature, pressure, wind direction and velocity, precipitation, etc.

The platforms are equipped with UHF reception and transmission capability. They are interrogated, i.e., activated to report, by the CDA station, which interrogates via the spacecraft on an S band frequency. The interrogation is frequency translated in the spacecraft to UHF, and transmitted to the DCP by a UHF transmitter in the spacecraft. The platform responds by transmitting its encoded data to the spacecraft at UHF. This response is frequency translated to S band in the spacecraft and transmitted to the CDA station.

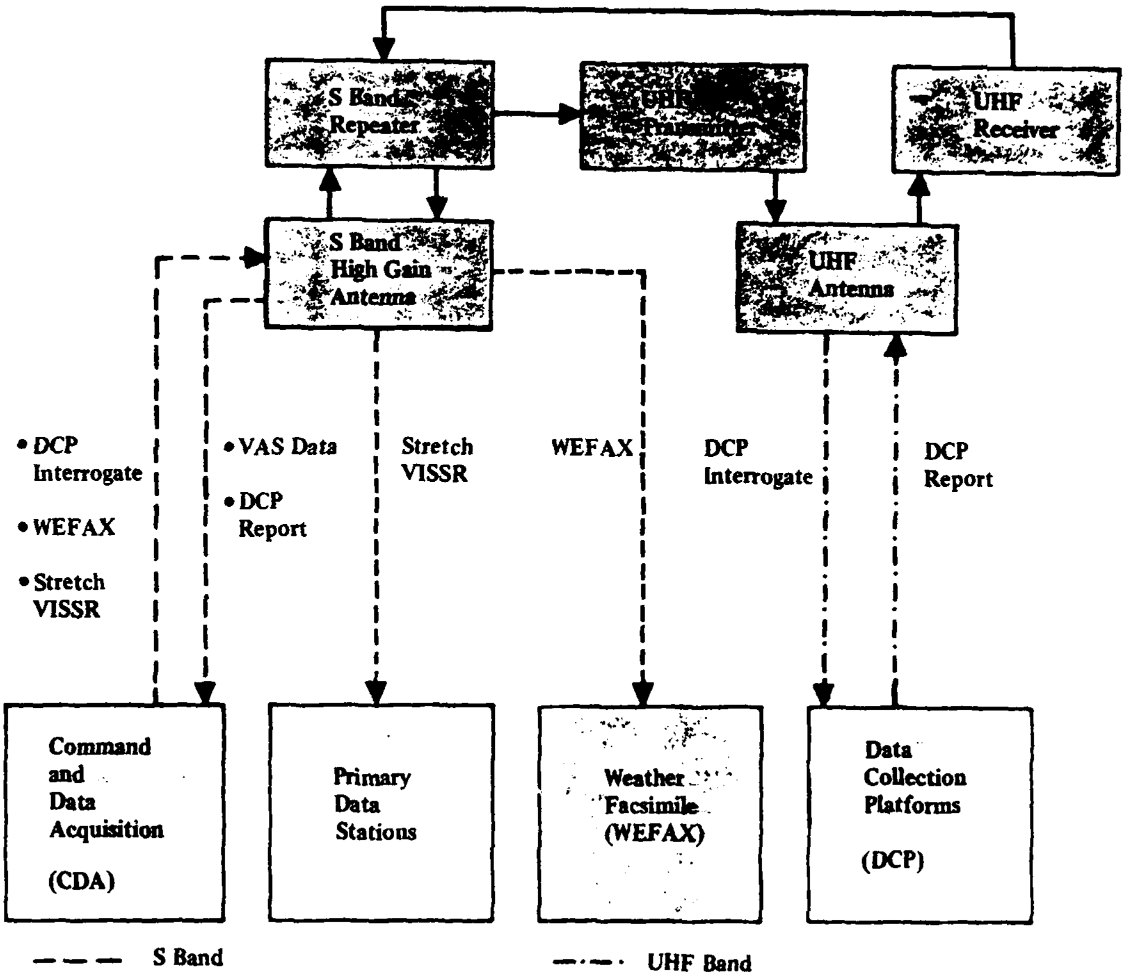
Stations are interrogated to make a synoptic survey of regional weather conditions. Each platform recognizes its assigned digital address and responds on its transmission frequency. Although the interrogation can be made in a few seconds, each platform requires about 30 seconds to respond. Therefore, many platforms may be responding simultaneously. The spacecraft is able to relay, simultaneously, 188 responding platform frequencies. Platforms also may be designed to transmit their information at a particular time, uninterrogated. They also may be designed to transmit, upon occurrence, a specific event which triggers the transmission.

The repeater channel for relaying DCP interrogations and replies is made functionally independent of the channels for handling other relayed information so that it may operate without interruption. The table, Spacecraft Standard Operating Modes, on page 2-7 shows that DCP relay is available at all times except that DCP interrogation is not available in the minimum power eclipse mode, E_2, where the UHF transmitter is turned off.

DATA RELAY INTERFACES

Characteristic	DCPR Repeater	DCPI Repeater	WEFAX and Stretch VAS
Uplink			
Antenna polarization	RHC	Vertical linear	
Spacecraft antenna type	Earth coverage	Earth coverage	
Frequency (channel), MHz	401.900	2034.925	
G/T, dB/°K	-18.5	-17.6	
Downlink			
Channel frequency, MHz	1694.500	468.850	1681.600
EIRP, dBm	35.6	46.2	56.1
Spacecraft antenna type	Earth coverage	Earth coverage	Earth coverage
Spacecraft antenna polarization	Vertical linear	RHC	Vertical linear

GOES



DATA RELAY LINKS

Communication Function

The modes of operation described on previous pages are implemented through the communication subsystem. Two receiving and three transmitting subsystems are used; they share only the tricoaxial rotary joint.

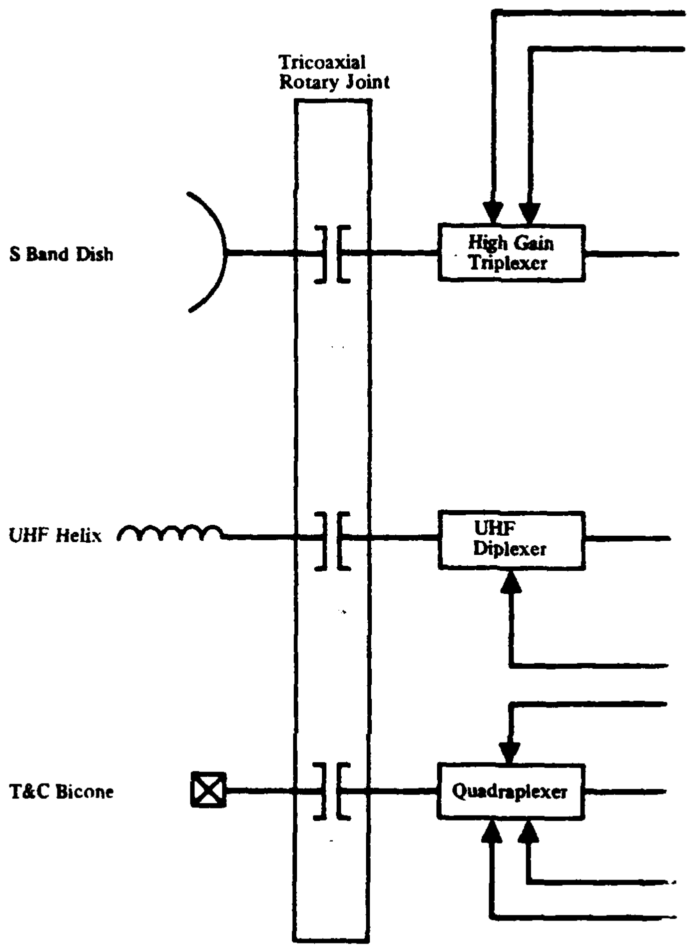
A separate subsystem is devoted exclusively to telemetry, command, and ranging. As shown, it uses the bicone, a separate antenna mounted on a mast above the despun UHF helix and S band reflecting antennas. The bicone provides a toroidal pattern, nondirectional around the spin axis and wide in the transverse axis to assure signal access in the transfer orbit during launch operations. The CDA station and STDN use the same frequencies for command and ranging, but for telemetry they use two different frequencies, which are accommodated by two telemetry transmitters, as shown. Switched redundancy is provided on all transmission channels. Transmitters are coupled to the bicone antenna through a quadraplexer and the tricoaxial rotary joint. Two transmitted power levels provided in the primary STDN telemetry transmitter permit a low power mode, during launch, to avoid corona breakdown in the critical pressure interval.

The major part of the communication subsystem consists of the S band 20 watt, class C, wideband, solid state transmitter and S band receiver used for data communication between the CDA station and the satellite; the UHF transmitter-receiver for communicating between the satellite and the DCP, and the low power (0.2 watt) linear S band transmitter for relaying the DCP replies from the satellite to the CDA station.

Direct transmission of VAS signals to the CDA, relay of stretch VAS and WEFAX data, and relay of ranging signals between CDA and the Turn Around Ranging System (TARS), are provided by the high powered repeater. These functions are mutually exclusive and must share the system according to the operating mode plan described earlier in this section.

Frequency translation of the DCP interrogate (DCPI) signal from S band to UHF is performed in circuits physically associated with the S band receiver. Similarly, frequency translation of the UHF DCP replies (DCPR) is done in the UHF receiver.

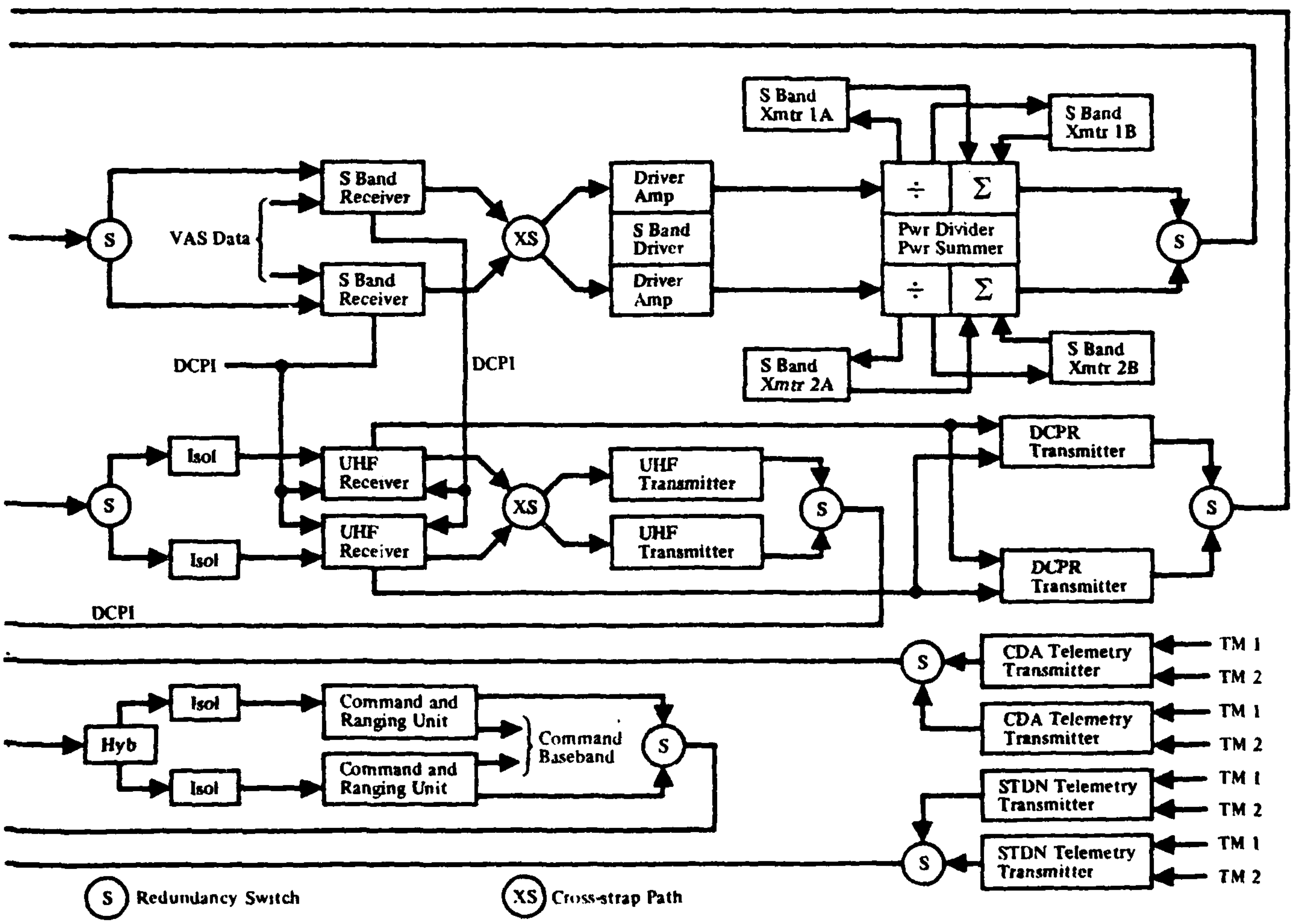
Because as many as 188 DCP replies may simultaneously pass through the DCP to CDA link, linearity must be preserved in this channel to avoid interference and distortion. Linearity is achieved by use of automatic gain control in the UHF receiver and by using an independent linear S band transmitter.



COMMUNICATION SUBSYSTEM CHARACTERISTICS

Mode/Parameter	Command	CDA Telemetry	STDN Telemetry	STDN Ranging	DCPR	DCPI	Multidata Transmission	VAS Data Transmission
	Function							
	Characteristics							
Uplink								
Spacecraft antenna polarization	Vertical linear			Vertical linear	RHCP	Vertical linear	Vertical linear	
Spacecraft antenna type	Toroid			Toroid	Earth coverage	Earth coverage	Earth coverage	
Channel frequency, MHz	2034.200			2034.200	401.900	2034.900	2030.000**	
G/T dB/K	-36.9/-38.9			-36.9/-38.9	-18.5	-17.6	-17.6	
Downlink								
Spacecraft antenna polarization		Vertical linear	Vertical linear	Vertical linear	Vertical linear	RHCP	Vertical linear	Vertical linear
Spacecraft antenna type		Toroid	Toroid	Toroid	Earth coverage	Earth coverage	Earth coverage	Earth coverage
Channel frequency, MHz		1694.000	2214.000	2209.086	1694.5	468.825	1688.000	1681.600
EIRP dBm		34.8	High 22.6* Low 10.7*	13.9/9.4*	36.5	46.2	56.1	55.5

*50° off-axis. **Nominal.

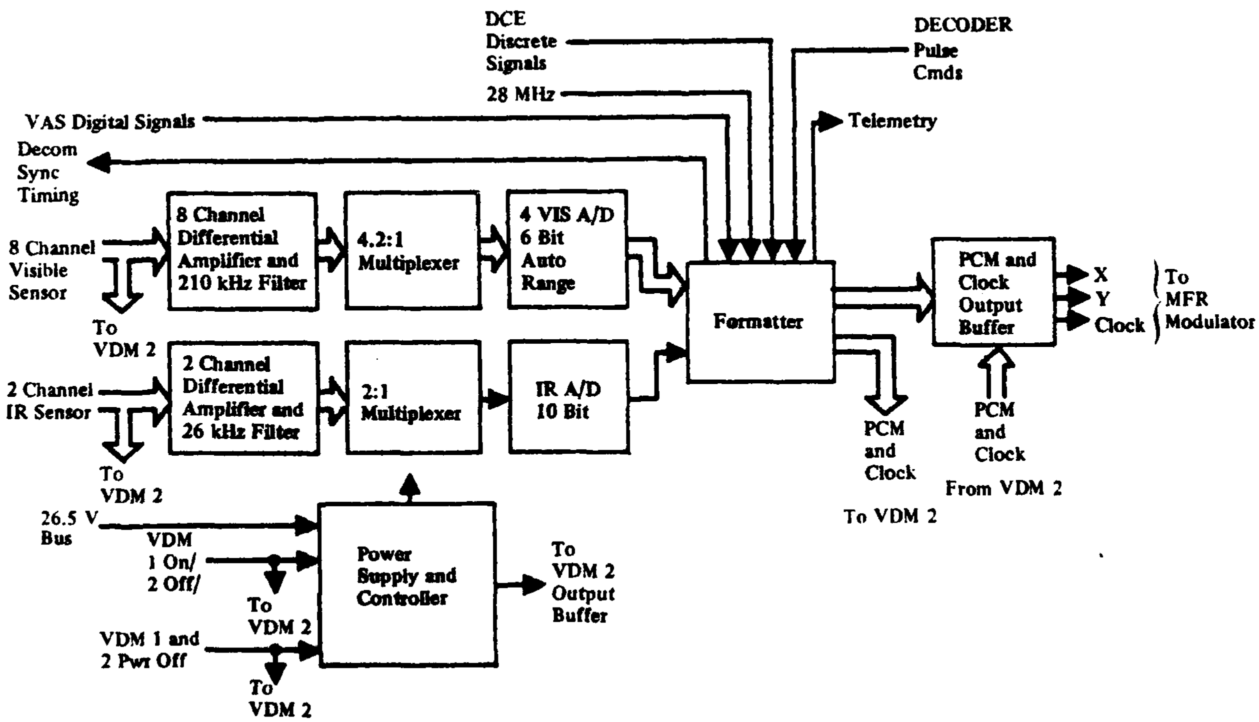


VAS Digital Multiplexer

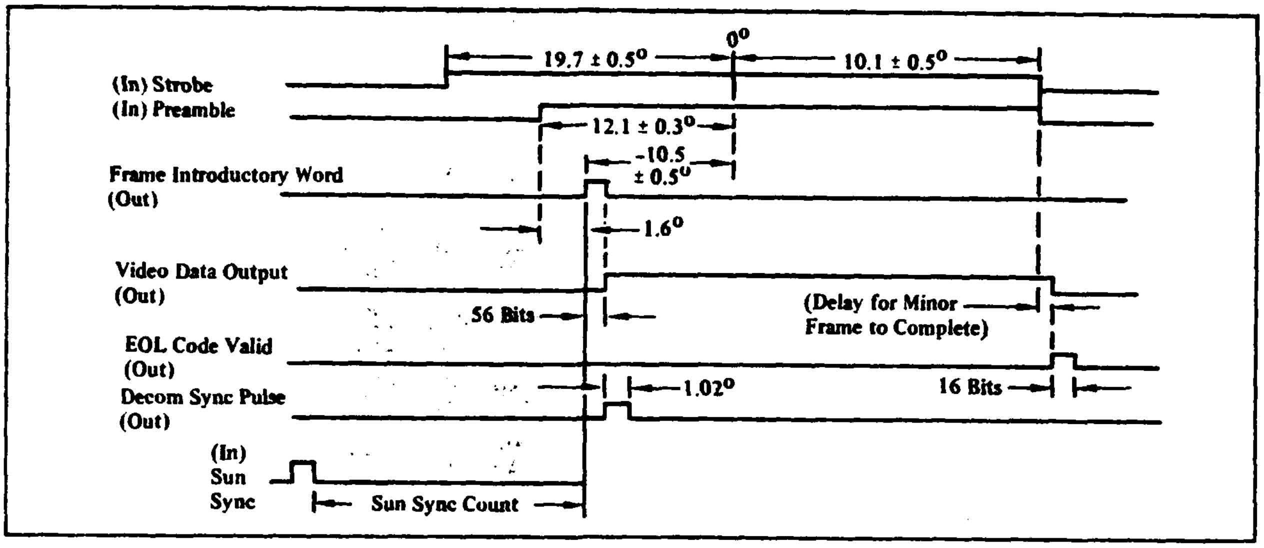
The VAS digital multiplexer (VDM) has two interrelated functions. One function is to convert the analog voltages from the VAS sensors, representing brightness of the IR and visible scenes, into digital bits which modulate the communication link for transmission of the scenes to CDA. The other function is to identify these bits in a transmission format by which they can be decoded at CDA and reconstructed into scenes. The format is established in the following manner:

Each scan line in the VAS has an identification code. The spacecraft attitude and orbit control subsystem, through its despin control electronics, determines the precise scan start and completion times related to the center of the earth. The scan line number code is combined with other data (PCM format, "Word 0") in a 56 bit word at the beginning of each scan line. The DCE starts transmission on the scan line by turning on the VDM with (In) strobe, as shown. After sufficient settling time has elapsed, the DCE starts the preamble of 1's and 0's. At the proper time it signals for the frame introductory word, "Word 0," which is read into the bit stream from the appropriate sources. The actual data sampling follows, repeating the four word sequence shown until it is terminated by the DCE with a signal for an end-of-line validator. On the next spacecraft revolution another line is similarly formatted and transmitted. The CDA demultiplexer recognizes the content of the "Word 0" and sorts out the data accordingly.

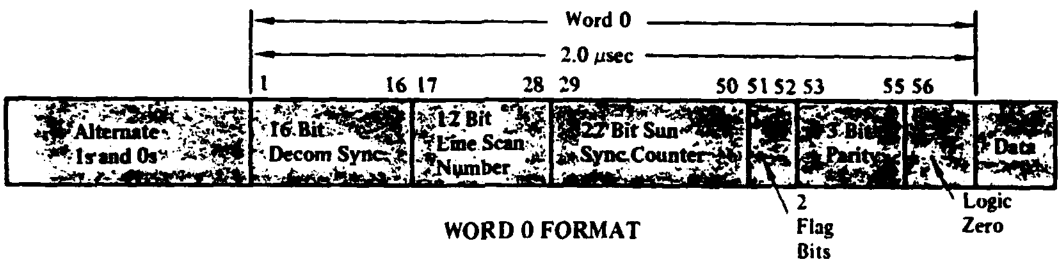
The sample clock rate is 28 Mbps. Visible data are quantized into 64 levels (6 bit) and IR data are quantized into 256 levels (8 bit). The four 56 bit word sequence permits about 500,000 samples per second of the visible channels or about 2083 samples per channel per scan line. Similarly, the IR sample rate is about 125,000 samples per second, resulting in about 4166 samples per scan line. (The 20° FOV and 100 rpm spin speed result in a nominal time of 0.03333 second duration for each scan line.)



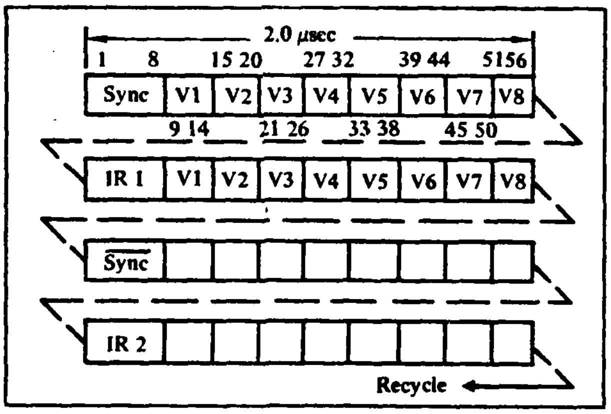
VAS DIGITAL MULTIPLEXER



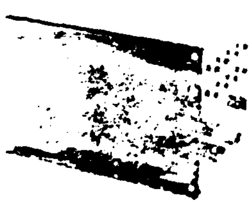
VDM REFERENCE TIMING



WORD 0 FORMAT

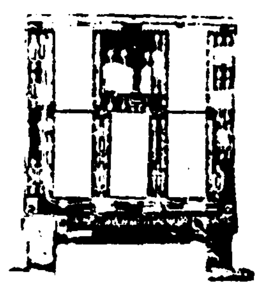


DATA SAMPLING FORMAT

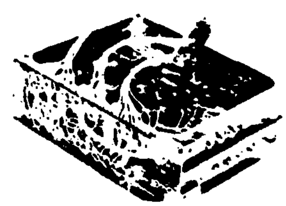


VDM

FORMATTER



A/D MODULE



POWER SUPPLY

Attitude and Orbit Control

Shown are the hardware components identified with the attitude and orbit control (AOC) subsystem and their relative locations in the spacecraft. The roles of the accelerometer and the hoop dampers are discussed elsewhere. (See Nutation Control and Damping.) The despin bearing mechanically attaches the despun antenna group to the spacecraft. In addition to bearings and mounting flanges, it contains a drive motor and indexing mechanism which are used in a feedback loop to keep the antennas trained on the earth while the spacecraft is spinning.

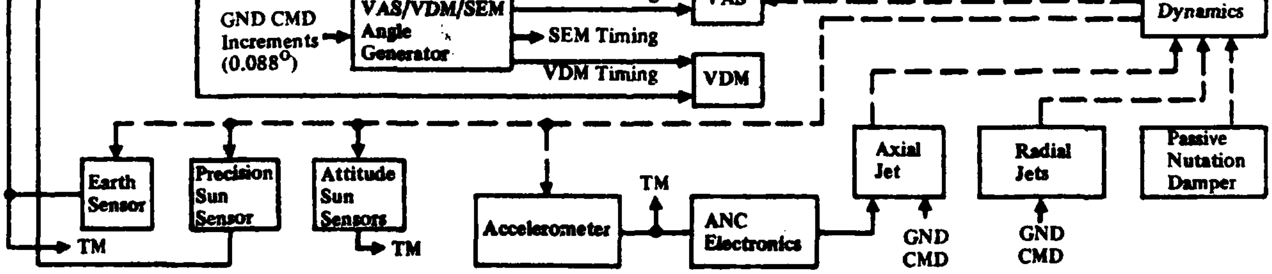
The earth and sun sensors and their associated electronic processing circuits provide lines of reference from the spacecraft to the earth and sun from which the spin axis attitude can be determined, and provide earth related references needed for spin angle related functions. The precision sun sensor provides the primary reference for generating spin angle related timing functions.

The functional interconnection of the AOC elements that perform antenna pointing, VAS/VDM/SEM timing, and nutation, attitude, and orbit control is illustrated. The heart of the system is the phase locked loop (PLL), which generates timing that is accurately phase controlled to the spacecraft rotor spin rate as defined by the sensor reference. The sensor reference may be selected by ground command as either the precision sun sensor (normal mode) or either of two earth sensors.

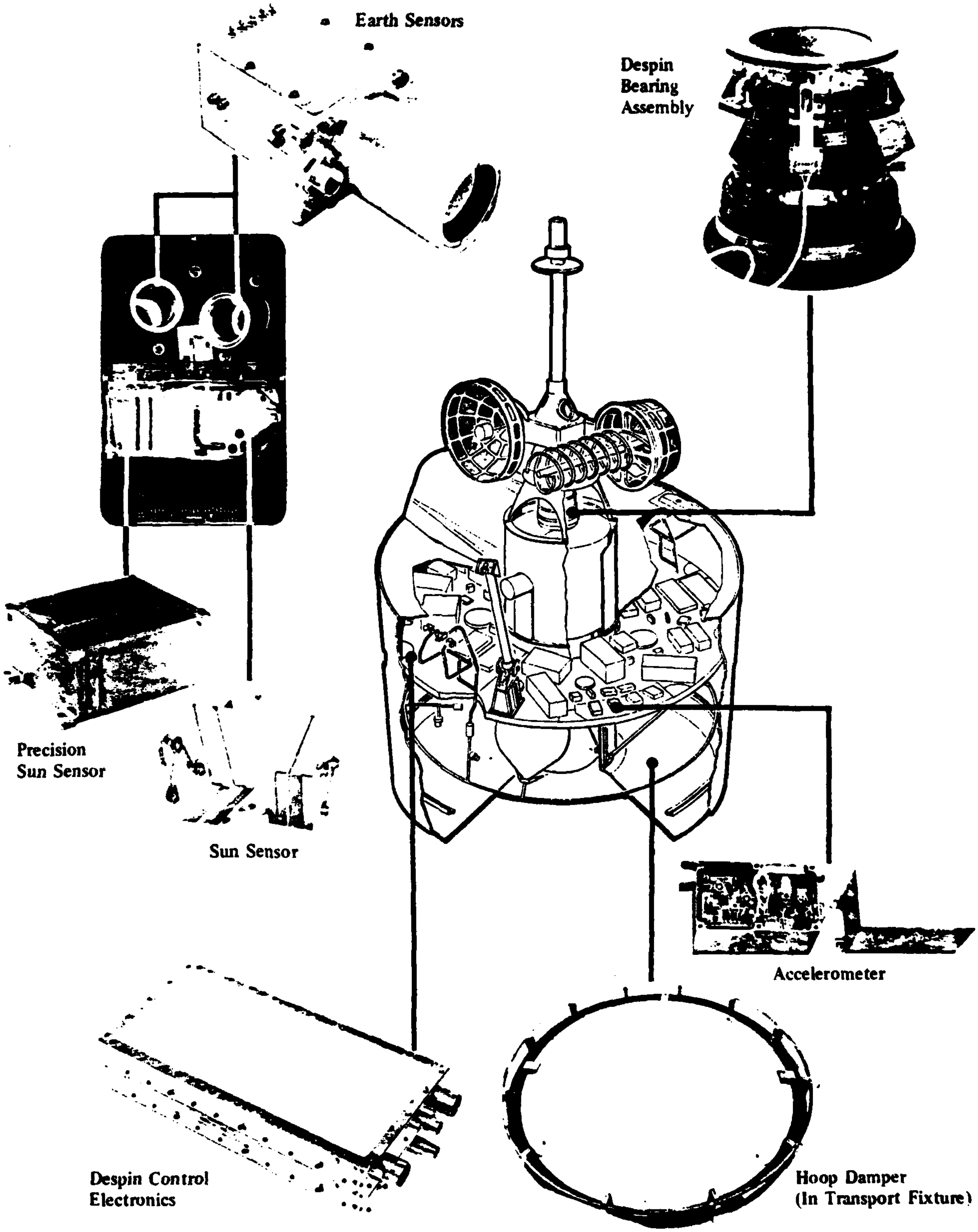
The selected sensor reference supplies a pulse train at spin frequency ω_s, with pulse positions carrying rotor inertial phase information. The pulse train is then processed by the PLL, which quantizes the spin cycle into 2^{16} (0.0055°) parts. In "sun" mode the PLL output pulse train is delayed by the time-of-day clock to account for the sidereal-solar time difference. The delayed output is pulsed at $2^{12}\omega_s$. In "earth" mode the delay function is inhibited. The TOD delayed output is then counted down and delayed in two angle generators to provide independent control reference for antenna pointing and VAS/VDM/SEM angle reference timing.

The antenna angle generator counts the $2^{12}\omega_s$ input pulse train down to $2^4\omega_s$ and provides for ground commanded pulse additions or subtractions that step the antenna reference in $\pm 0.088°$ increments with a range of $\pm 180°$. Its output then contains rotor phase information, ω_s, plus any desired pointing bias, on a pulse train which is compared with the pulse train from an index pulse generator, incorporated in the DBA, providing rotor-to-antenna relative phase measurements. The phase difference of these two pulse trains provides the error signal for the antenna despin servo.

The VAS/VDM/SEM angles generator provides a stream of eight timing signals in each spin period to synchronize the required mission line-scan operations with rotor spin phase.



CONTROL SUBSYSTEM FUNCTIONAL DIAGRAM



ATTITUDE AND ORBIT CONTROL SUBSYSTEM

Spacecraft Characteristics

The table sets forth the major characteristics of the spacecraft subsystems other than the VAS and SEM, whose subsystem characteristics appear earlier in this section.

Launch Vehicle	Delta 3914
Spacecraft Mass, lb	
Launch (separated spacecraft)	1841.0
On station – beginning of life	874.0
On station – end of life (dry weight)	762.0
Spacecraft Dimensions, in.	
Length along Z-axis	174.3 (with adapter) 138.7 (without adapter)
Diameter	84.5
Apogee Motor	Thiokol TE-M-616 derivative
Communications	
Coverage at S band Coverage at UHF	Visible earth-western hemisphere
Frequencies	

Multifunction Repeater	Multifunction/VAS	WEFAX	Trilateration
Receive, MHz	2029.1 (S VAS)	2033.0	2026.0 2030.2 2032.2
Transmit, MHz	1681.6 (VAS) 1687.1 (S VAS)	1691.0	1684.0 1688.2 1690.2

Frequencies	MFR	DCPI	DCPR	CDA TM	STDN TM	STDN RNG	STDN/CDA CMD
Receive, MHz	See	2034.925	401.9	–	–	2034.2	2034.2
Transmit, MHz	above	468.850	1694.5	1694.0	2214.0	2209.086	–
EIRP, dBM	56.1	46.2	35.6	33.4	26.6	13.9	–
Margins, dB*	3.3	9.1	10.0	6.9	7.8	11.4	–
G/T, dB/°K	-17.6	-17.6	-18.5	–	–	-36.9	-36.9
Margins, dB	7.4	7.4	6.5	–	–	3.1	3.1
Bandwidth, MHz	8.2/20	0.2	0.4	0.1	0.1	1.0	0.08

Antennas	
S band (high gain)	Parabolic, linear (vertical) polarization – 18.2/18.1 dB peak gain transmit/receive
UHF	Helix, RHCP – 11.7/9.4 dB peak gain transmit/receive
S band (T&C)	Bicone-linear (vertical) polarization – 1.0/3.0 dB peak gain transmit/receive
Antenna Pointing, deg	
East-west	$<\pm 0.5$ (sun reference) $<\pm 0.75$ (earth reference)
Attitude Control and Stationkeeping	
On-orbit spin to transverse inertia ratio (EOL)	$\pm 1.13\ I_{ZZ}/I_{TEFF}$
On-orbit spin stabilized	*On-orbit spin rate: 100 rpm*
Attitude	Axial jet control to $\pm 0.2^{\circ}$
N-S stationkeeping	Axial jet control to $\pm 1.0^{\circ}$
E-W stationkeeping	Adjacent pair of radial jets for control to $\pm 0.5^{\circ}$
Spin rate	Moment pair of radial jets for control to ± 5 rpm
Transfer orbit spin stabilized	
Transfer orbit	Spin rate 55 rpm
Attitude control	Axial jet control with automatic nutation control. Time constant <10 sec
Active nutation control moment	3.7 ft-lb
Predicted stability margin	$>1500{:}1$ at threshold (0.2°) (T dedamp/T damp)
Fuel usage	1.0 lb (9 orbits)
Attitude determination	
Sensors	Earth and sun
Accuracy	$<\pm 0.1^{\circ}$ (on-orbit) $\pm 0.5^{\circ}$ (transfer orbit)

Propulsion	
Propellant	N_2H_4
Construction	Welded titanium
Number of tanks	3
Propellant capacity	
Flight load	226.8 lb
Pressure	350 psia initial, blowdown to 56 psia final
Number of thrusters	6
Nominal thrust level	1 lbf
Telemetry	
PCM telemetry	
Fully redundant	
Capacity	512 redundant TM point inputs
Frame rate, bit rate	3.06 sec/frame, 188.24 bps
Telemetry format words	64 word mainframe; one 64 word and three 32 word and one 16 word subcom frame
Word size	9 bits
Modes	PCM, FM real time; dwell and inhibit provided in PCM mode
Real Time Telemetry	
IRIG 12	Group 1 ABM fire, ANC fire, nutation data Group 2 Main bus current Group 3 VAS-PDL verification
IRIG B	Group 1 Sun pulse, earth pulse, execute, idle Group 2 Sun pulse, earth pulse, index pulse, idle
Command	
Fully redundant	
Command capacity	254 redundant pulse outputs, 1 redundant serial output
Receiver selection	Frequency and amplitude threshold discrimination
Bit rate	128 bps
Word length	8 bits address; 8 bits command
Driver circuits	92
Electrical Power	24.5 to 28.5 V; bus limiters clamp bus voltage at 28.5 V
Main bus regulation	Combination of series regulator and constant power individual load power supplies
Solar array configuration	One cylindrical panel 84.5 in. dia x 58 in. long, Type K-7 cells (2.2 x 6.2 cm with 9 mil coverglass) (6200 total) 384 cells in each charge array (768 total, 2.0 x 2.0 cm)
Solar array power, end of life (equinox)	350 W at 7 yr
Solar array power, end of life (summer solstice)	330 W at 7 yr
Battery charging (end of life)	High rate charging at 0.459A Intermediate charging at 0.291A Trickle charging at 0.105A
Number of batteries	2 (6.0 A-hr each), 27 cells/battery
Thermal Control	
Passive design with heaters to meet special requirements	
Configuration	VDA teflon radiator system on N-S faces Multilayer body and mast insulation with aluminized Kapton and Mylar blankets Propulsion valve and line heaters; ABM heaters
Spacecraft steady state internal bulk temperature range	5^{o} to $30^{o}C$
Reliability	
Design lifetime for consumables	7 yr

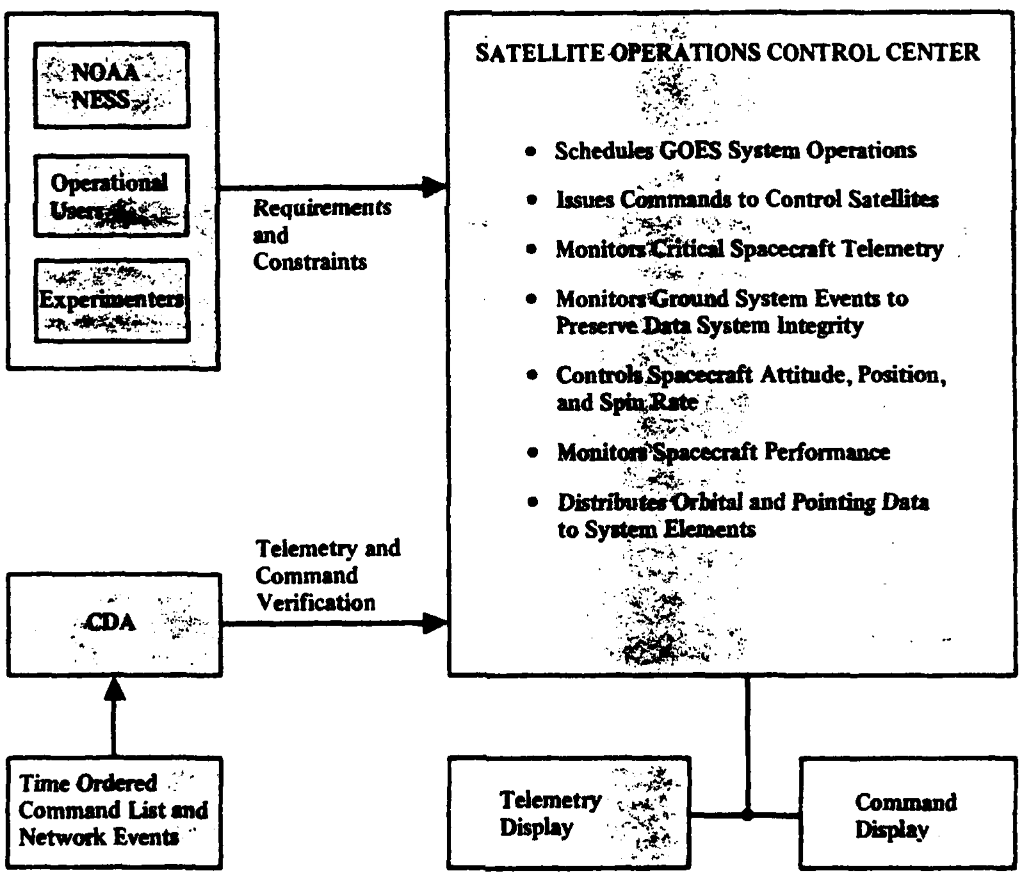
*Total link margins.

Satellite Operations Control Center

The Satellite Operations Control Center (SOCC) in Suitland, Maryland, is the focal point for GOES mission operations. It is responsible for continuous monitoring, evaluation, and operational supervision of the spacecraft data acquisition system.

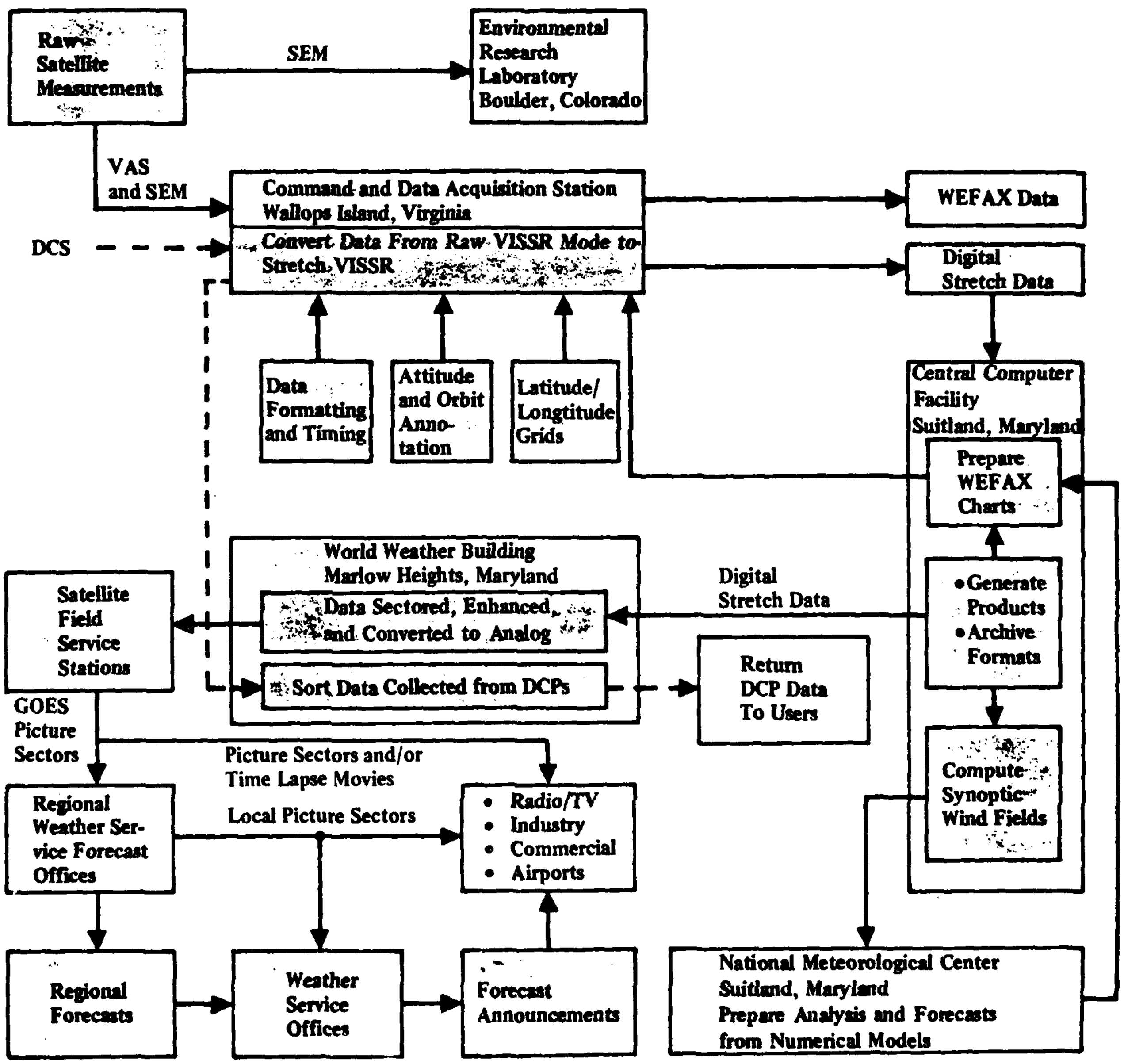
SOCC plans and schedules spacecraft and ground system activities to satisfy the mission requirements. The activity plan is a time-ordered list of spacecraft, sensor systems, and network events. Instructions from the SOCC originate in a command and control console which is staffed by a system controller responsible for technical direction and operation of the system. The console has displays as well as communications and data terminals to provide centralized system monitoring and control.

Spacecraft commands are sent to the Command and Data Acquisition (CDA) station for transmission to the spacecraft. Spacecraft telemetry and command verification is monitored by the SOCC to determine and maintain the state of health of the spacecraft and sensor systems. The spacecraft telemetry stream and station events are relayed from the CDA station to the operations support computer at SOCC. The controller in SOCC may select a complete telemetry display or a display of groups of individual telemetry points from particular subsystems. Ground station events can be displayed or combined with telemetry to display commands, as transmitted to or as received by the spacecraft, and the times of execution of all commands. Approximate assessment of spacecraft attitude may be obtained by display of data from the sun/earth data processor.



GOES Process Flow

The accompanying flow chart summarizes the sequence of processes applied to meteorological information collected by GOES in preparing that information for dissemination and practical use. In subsequent discussions related to the facilities of the GOES terrestrial complex, these processes are explained in more detail.



GOES OPERATIONAL PROCESS FLOW

Command and Data Acquisition

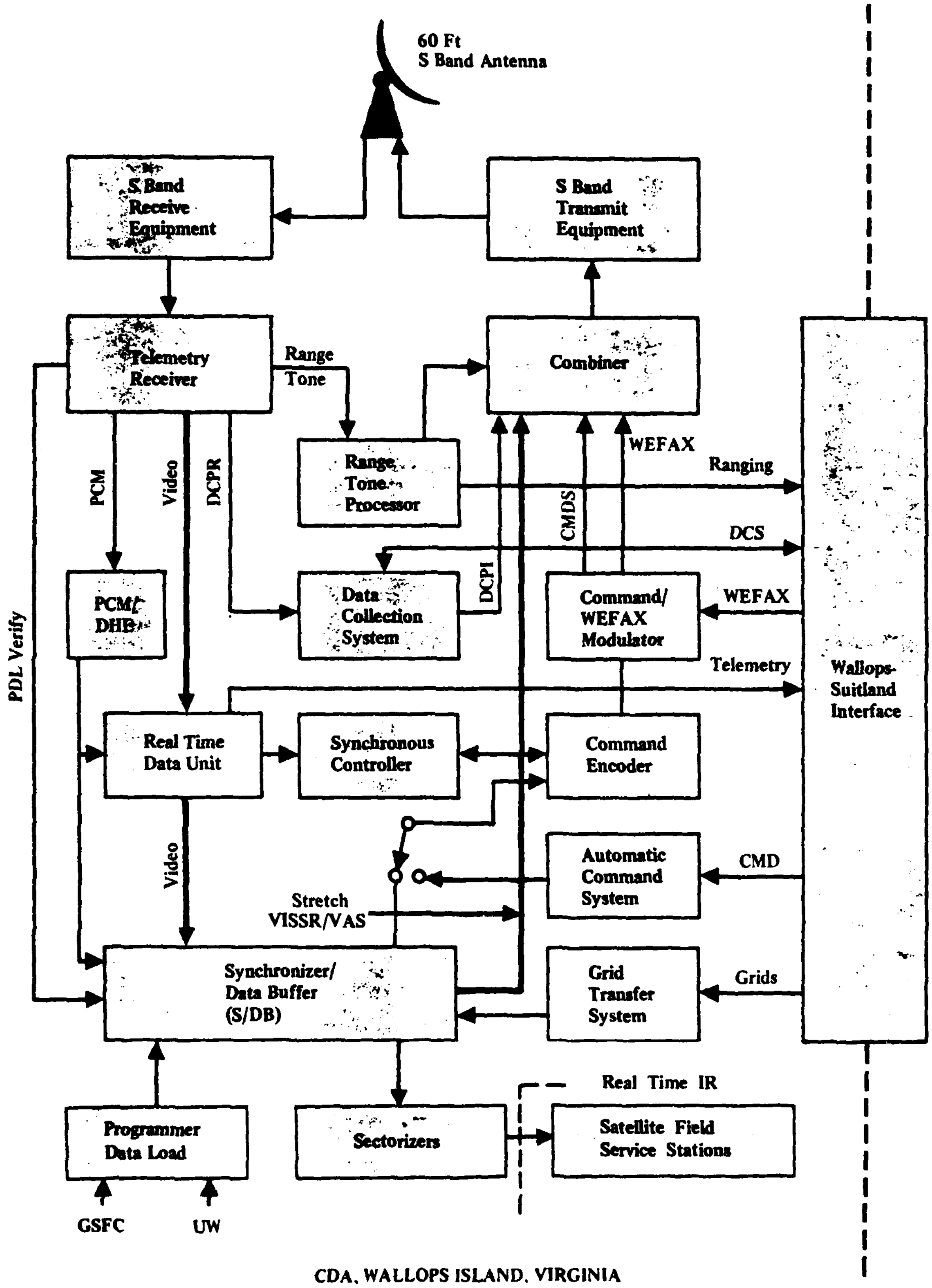
The Command and Data Acquisition (CDA) station is the terrestrial interface with the GOES satellites. It commands both GOES East and GOES West and receives telemetry and VAS data from both satellites. It is capable of receiving and processing the VAS raw data stream.

Satellite data transmissions, all arriving on S band carriers, are collected by the CDA receiving system and routed to the telemetry receiver, where the carriers and subcarriers are sorted, demodulated, and routed to their usage destination. The ranging, telemetry, and data collection information is sent to NESS at Suitland, Maryland. The VAS video data stream is routed to the synchronizer/data buffer (S/DB) within the CDA station. The S/DB, with input from other facilities, is configured to process these data for noise reduction, standardized message structure, and annotation with timing and gridding data. It reformats the processed data in the stretch VAS format and transmits them to GOES satellites which broadcast the stretch VAS to various centers. Gridding and annotation data are provided by the VISSR Image Registration and Gridding System (VIRGS) computing facility and inserted into the stretch VAS format by the S/DB.

During periods set aside for the VAS experimental demonstration, both Goddard Space Flight Center and the University of Wisconsin will be able to load commands via land lines into the S/DB to control the VAS instrument.

The CDA station issues commands and trilateration ranging transmissions as prescribed by SOCC. Commands originate at SOCC and are transmitted to the CDA station where they are incorporated into the automatic command system. Here a time-ordered list of command sequences to be released at appropriate times is maintained, and command execution is aided by a synchronous controller which assures command arrival at the spacecraft at the proper time in the spacecraft spin cycle.

As scheduled by SOCC, the CDA transmits to GOES Weather Facsimile (WEFAX) imagery provided by the National Environmental Satellite Service (NESS). The satellites then rebroadcast the WEFAX to users in the GOES coverage regions.



CDA, WALLOPS ISLAND, VIRGINIA

Preprocessing VAS Data

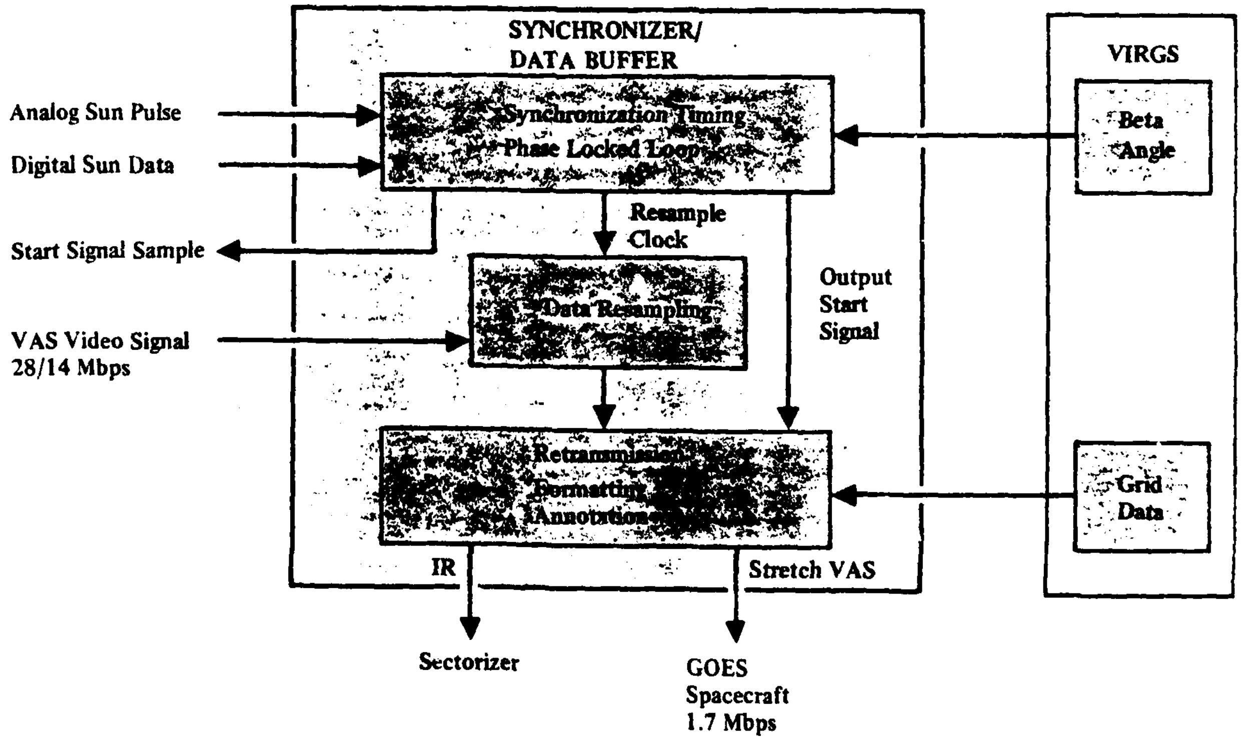
Prior to distribution to users, VAS data (VISSR Mode) are processed at the CDA for increased usefulness. The S/DB performs the key actions, separating the digital bit stream into visible, IR, and format identification channels.

The motion induced by scan stepping, filter wheel stepping, tolerance on satellite spin speed, and tolerance on line scan start in the satellite may cause the number of data bits in a scan line and the start of each scan line relative to earth's center to vary slightly from line to line. To standardize the bit content and start time of stretch VISSR data scans, data are resampled in the S/DB, using interpolation between bits to minimize degradation of original data. The resample scheme yields a definite number of bit samples and a uniform start time for each scan, greatly simplifying subsequent processing of the data.

After resampling, visible data are stored in the visible data buffer for stretch retransmission and are processed into four resolution grades for transmission to NESS by land lines for distribution to various users. IR data are fed to the S/DB computer for resampling, merging with gridding data, and insertion of fiducial marks and annotations. Low resolution visible data also may receive this treatment in the S/DB computer. Although visible and IR sensors each scan the entire earth scene, data are sampled at separate times due to the physical arrangement of the detectors. The S/DB rearranges the time sequence of these data so that, in the stretch VISSR transmissions, IR and visible images of a terrestrial point occur at identical locations in the two formats.

The S/DB reassembles the visible, IR, and identification data for transmission to the satellite at a lower bit rate, between VAS scans of the earth. The satellite broadcasts the data to primary users.

Earth gridding information, spacecraft orbit and attitude parameters, operating status, frame time identification, and other housekeeping data are documented in the stretch data format. Earth location grids calculated by VIRGS and forwarded to the CDA station are inserted in the stretch data as a ninth bit to each IR sample. The S/DB also formats the stretched IR data into lower resolution modes for various purposes and has the capability to sector data for certain usages. The lower resolution IR data are formatted for analog transmission, by telephone lines, directly to the satellite field service stations and the central data distribution facility (CDDF).



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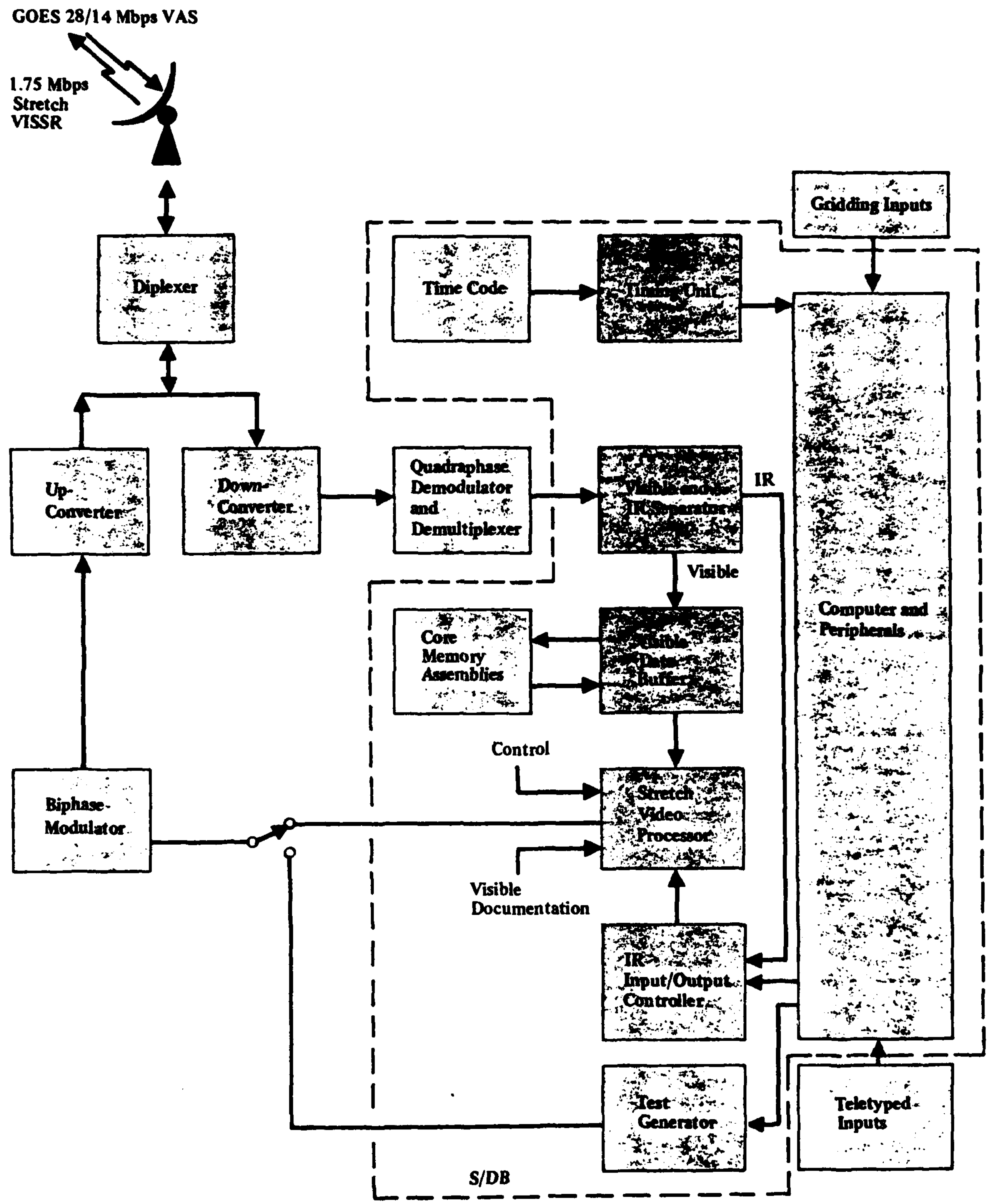


SIMPLIFIED BLOCK DIAGRAM
S/DB PORTION OF CDA STATION

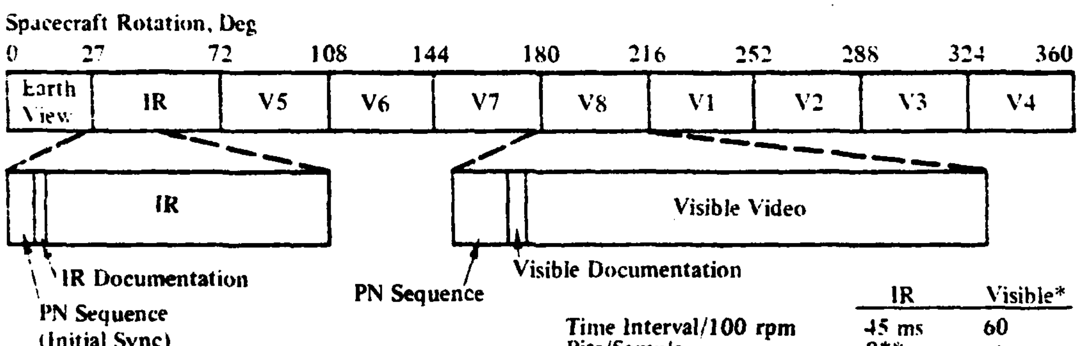
Stretch VISSR/VAS Data Format

The VISSR/VAS data are acquired and transmitted during the 33.33 ms interval when the GOES satellite, spinning at 100 rpm, sweeps the VISSR/VAS detectors across the 20° angle centered on the earth. This burst of raw data is processed in the S/DB and the 18.375° portion containing terrestrial image is retransmitted through the GOES in the remaining 340° of the spin cycle. The stretch formats of both VISSR and VAS data are compatible, but some differences related to the IR portion arise because of the need to accommodate the VAS multispectral imaging mode. The illustration on the opposite page shows the principal stretch data mode formats for VISSR and VAS.

In the VISSR format, to provide for necessary tolerances and control delays, an allowance of 7° (11.67 ms) is added to the 20° for transmission of the raw data burst, setting the available angle for retransmission at 333° (555 ms). As shown in the illustration, retransmission intervals of 36° (60 ms) are allotted to each of the eight visible spectrum channels and 45° (75 ms) is allotted to the IR channel (either primary or redundant). These intervals are selected to be compatible with a drum-type image recorder — i.e., the drum and satellite spin speeds and the duration of the data intervals must synchronize. The time interval is based on a satellite spin rate of 100 rpm. At other rates the angle intervals are *retained and the time intervals are adjusted as required.*

In the VAS format, two IR scan lines must be transmitted to accommodate the scan patterns of the multispectral imaging mode. Also, ten bit words must be accommodated in some conditions. More documentation must be used in the VAS format. The IR portion of the VISSR stretch data pattern is readjusted as shown in the illustration. It is split into two angular intervals of 21.7° and the leftover 1.6° is added to the earth-view interval. The bit rate is raised to 1,747,200 bps, equal to the visible bit rate. Documentation words and end of line code (EOLC) words are added. The number of IR documentation words required in Mode AA is substantially greater than in Mode A and consists of documentation for individual channels as well as common documentation.

Three VISSR formats are available in addition to VISSR Mode A, the normal operational mode. These modes are characterized, in comparison with Mode A, in the accompanying table. All modes convey normal 4 mi x 2 mi IR. Mode B provides 1 mi x 1 mi visible video obtained by averaging adjacent visible signal scans (e.g. V_5, V_6) and transmitting the averaged signal at a reduced sample rate in 72° intervals. Mode C provides visible video of 4 mi x 4 mi resolution obtained by averaging all eight channels and transmitting the averaged video at a reduced sample rate during a 288° interval. Mode D provides normal IR and IR of 4 mi x 4 mi resolution obtained by averaging the primary and the redundant IR sensor signals and transmitting them at a reduced sample rate during a 288° interval. The reduced resolution data of Modes C and D are transmitted in eight bit words which contain two bits of implanted gridding message.



	IR	Visible*
Time Interval/100 rpm	45 ms	60
Bits/Sample	9**	6
Bit Rate/100 rpm, bps	524,160	1,747,200
Initial Sync, Words	418	1672
Documentation:		
IR	128	–
IR Common	–	–
Visible	–	512
Words:		
Video	3822	15,288
EOLC	–	–
Total	4368	17,472

*Each Interval

**with gridding

STRETCH VISSR FORMAT – MODE A

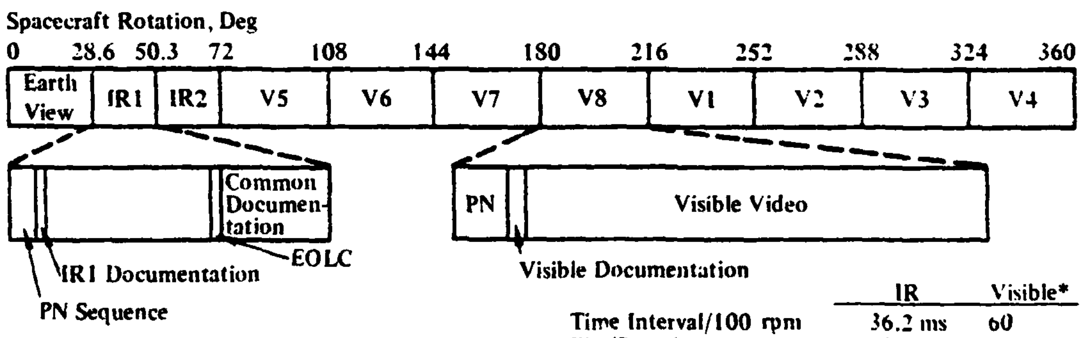
In both formats, the earth-view interval is filled with words of alternating zeros and ones, nine bit words for VISSR and 10 bit words for VAS.

A basic clock frequency of 10,483,200 Hz is used to synchronize the S/DB and all bit transmission rates are coherently derived from it. Visible data bits are 6 clock pulses in duration resulting in a rate of 1,747,200 bps for visible video. In the VAS Mode AA both visible and IR data are retransmitted at this rate. In the VISSR Mode A the IR is transmitted at one twentieth clock frequency or 524,160 bps. In other VISSR modes, transmissions are made at clock frequency divided by 24 (Mode B) and clock frequency divided by 315 (Modes C and D). Data users also decode the bit stream using the basic clock frequency and coherently derived submultiples.

The retransmitted data is a serial bit stream passed through an NRZ-S differential encoder which produces a transition for each logic zero input and no transition otherwise. The most significant bit is transmitted first. The differentially encoded bits biphase-modulate the uplink carrier.

STRETCH VISSR DATA MODES

Parameter	A	B	C	D
Word length, bits				
Visible	6	6	8	–
IR (regular)	9	9	9	9
IR (averaged)	–	–	–	8
Resolution, miles				
Visible	1/2 x 1/2	1 x 1	4 x 4	–
IR (regular)	4 x 2	4 x 2	4 x 2	4 x 2
IR (averaged)	–	–	–	4 x 4
Bit rate, bps				
Visible	1,747,200	436,800	33,280	–
IR (regular)	524,160	524,160	524,160	524,160
IR (averaged)	–	–	–	33,280
Words				
Initial sync	1,672	836	69	69
Documentation	512	256	16	16
Video	15,288	7,644	1,911	1,911



	IR	Visible*
Time Interval/100 rpm	36.2 ms	60
Bits/Sample	10	6
Bit Rate/100 rpm, bps	1,747,200	1,747,200
Initial Sync, Words	424	1672
Documentation:		
IR	16	–
IR Common	2048	–
Visible	–	512
Words:		
Video	3822	15,288
EOLC	8	–
Total	6318	17,472

*Each Interval

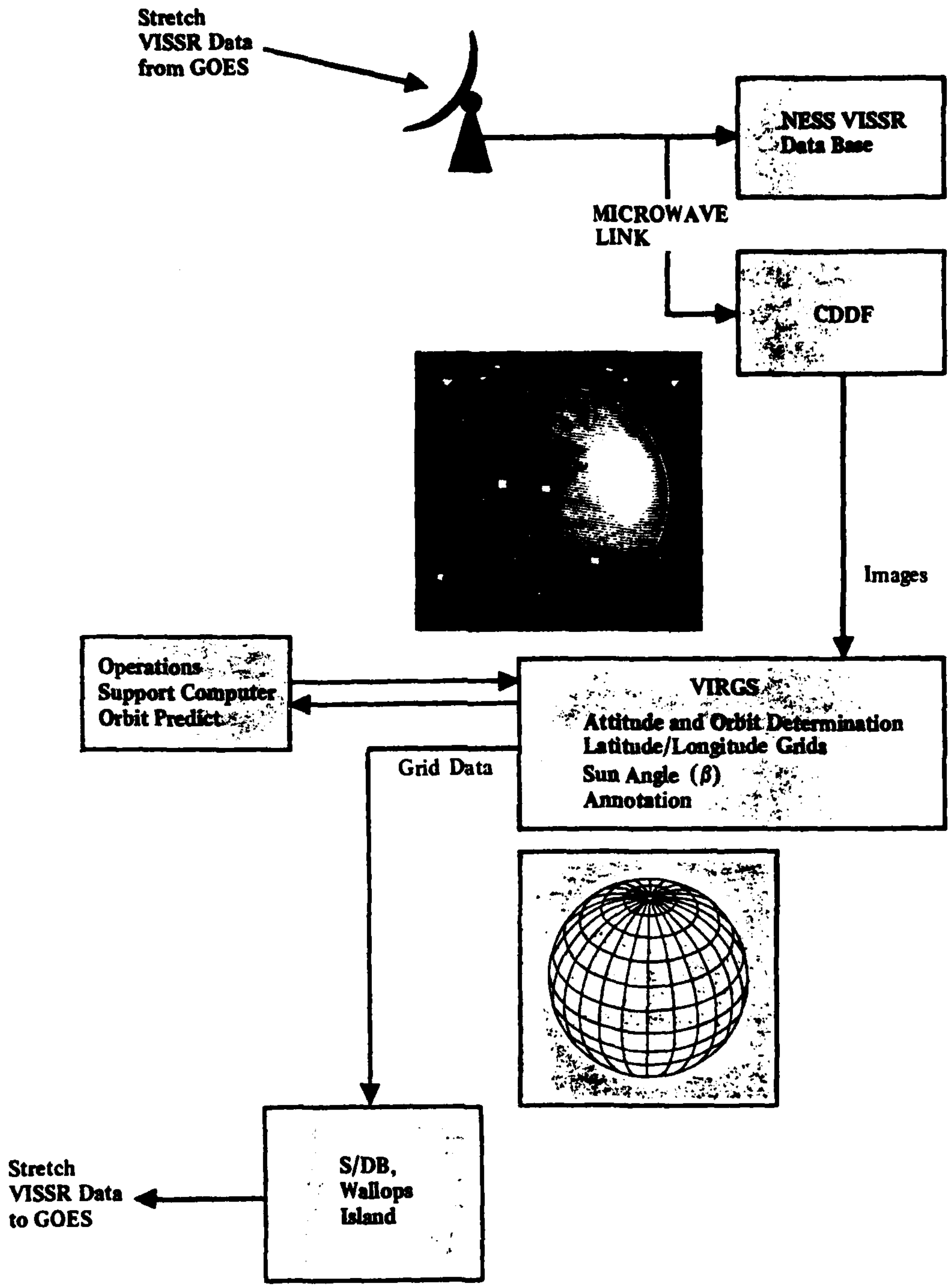
STRETCH VAS FORMAT – MODE AA

Data Documentation

The annotation, grid markings, and geometry-related inputs to the S/DB are computed by the VISSR image registration and gridding system (VIRGS) located in the World Weather Building, Marlow Heights, Maryland. VIRGS communicates with NESS via a microwave link.

Markings are inserted into an extra bit provided in the S/DB stretch data words. To determine which bits in a scan must be filled with gridding or fiducial marks, VIRGS, using a three-dimensional geometrical model of the earth, satellite position, satellite spin-axis orientation, and sun, must calculate the coincident time of a marker bit and an earth image word. Required for this calculation are the orbit of the satellite and its spin axis orientation. Orbit and attitude information are obtained from the CDA range and range rate measurements and from reduction of the sun and earth data which are provided to VIRGS via NESS. Orbit and attitude information may be extracted from the VISSR data base also. The two sources of information are used to refine the precision of the calculations.

To perform the calculations from data base, a GOES full scan disk image is obtained. Several stars are selected from the image background in the polar region. The known coordinates of these stars are used to specify satellite attitude. These data, together with the position of two or more recognizable landmarks in the VAS image, enable determination of the orbit. Repeating the procedure on another image and subtracting the results produce attitude and orbit rates. Solutions of the mathematical model predict the attitude and orbit as a function of time from the initial measurement. The "BETA" angle, used in synchronizing transmissions to the satellite, is determined from the orbit data. Files of BETA, earth grids, and annotations for each picture are sent to the CDA station for use by the S/DB, which interleaves the grids and annotations into the stretch VISSR image data.

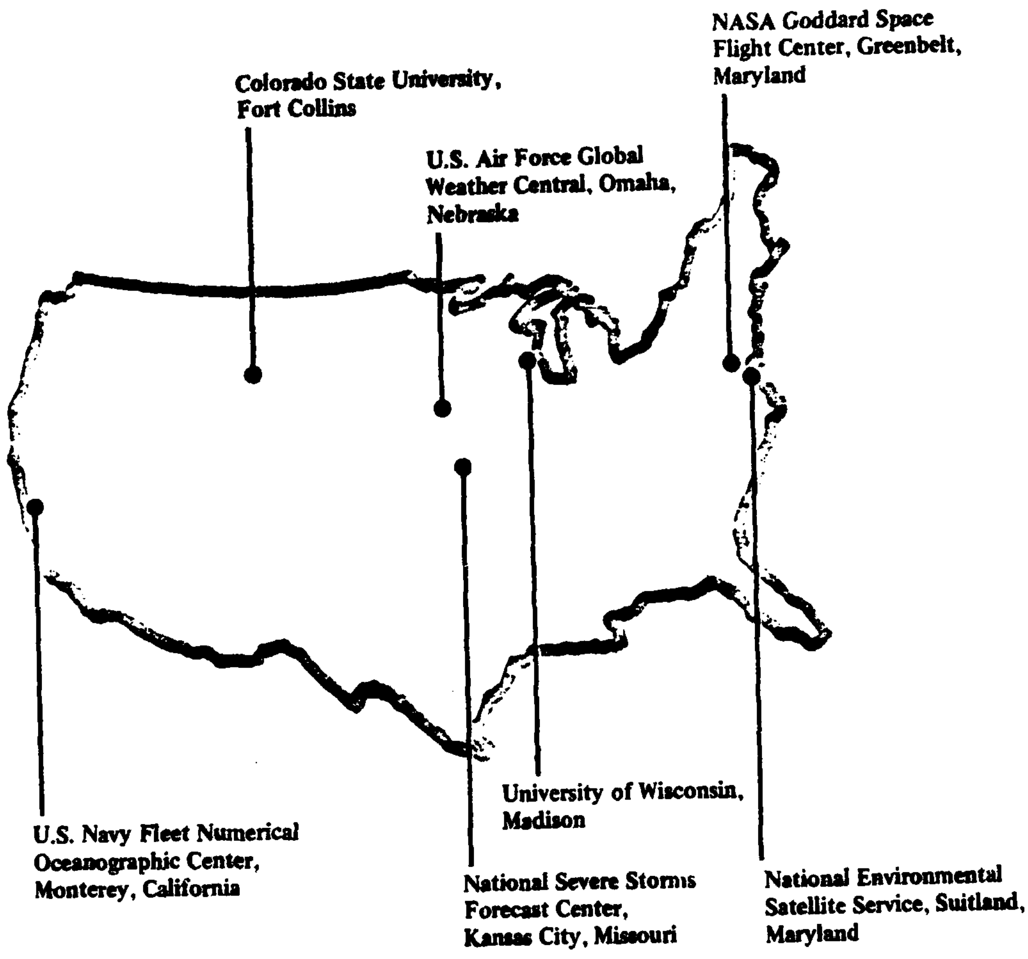


STRETCH VISSR DOCUMENTATION FLOW

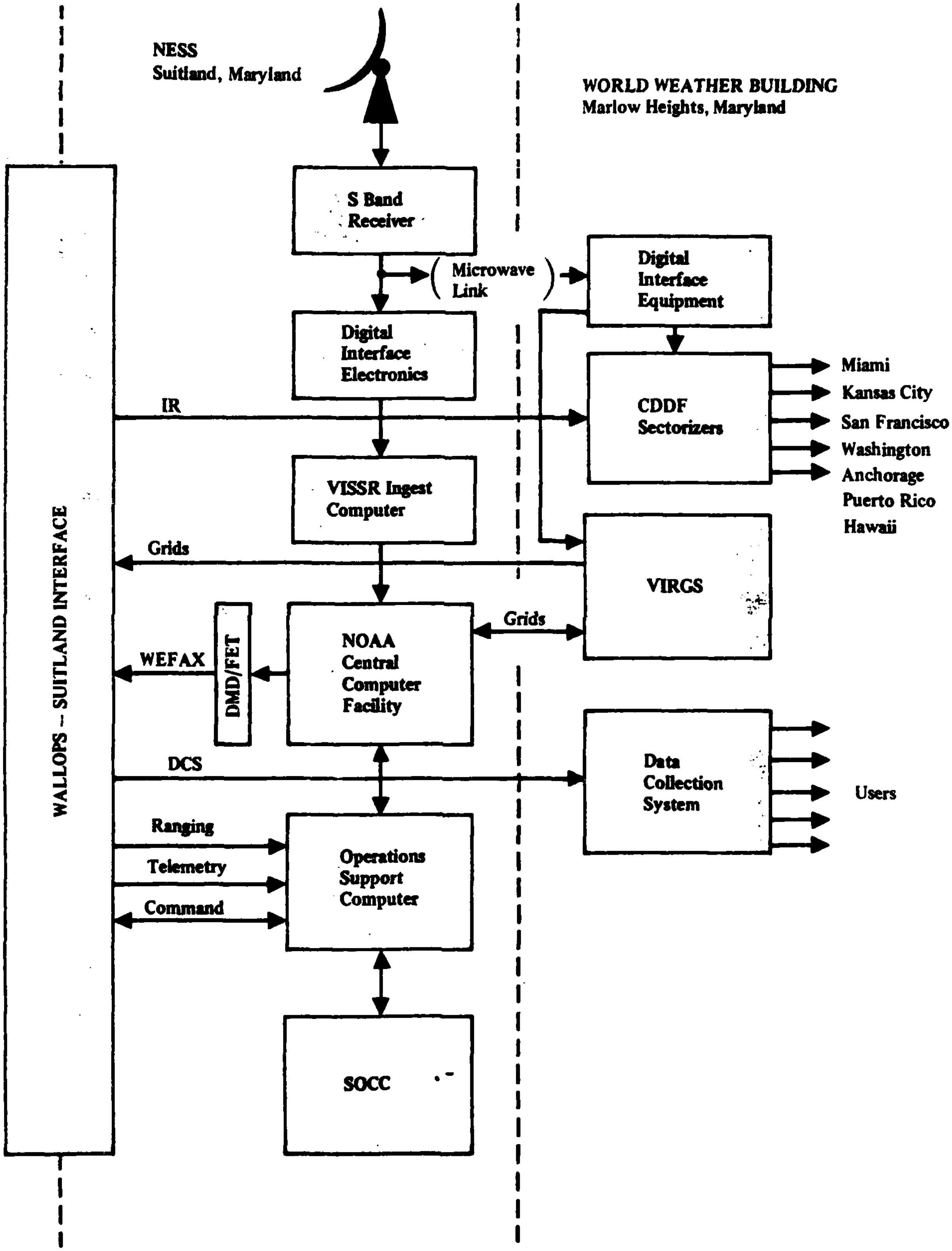
VISSR Data Distribution

NESS processes stretch VISSR mode data and distributes cloud and IR image products. Incoming data from the satellite are passed from the NESS receiving station to two functional entities, the VISSR ingest computer and the CDDF. The VISSR ingest computer (VIC) builds the data base accessed by the National Oceanic Atmospheric Administration (NOAA) IBM system for applications. The CDDF extracts from the total high resolution, full disk data, selections of specified geographical areas in resolutions of 0.9, 1.9, or 3.7 km (½, 1 or 2 n.mi.). These sectors are formatted for analog transmission over telephone lines to Satellite Field Service Stations.

Stretch VISSR data broadcasts by GOES are available to users with suitable receiving equipment. Some users are identified and located in the accompanying map of the United States.



STRETCH VISSR DATA USERS



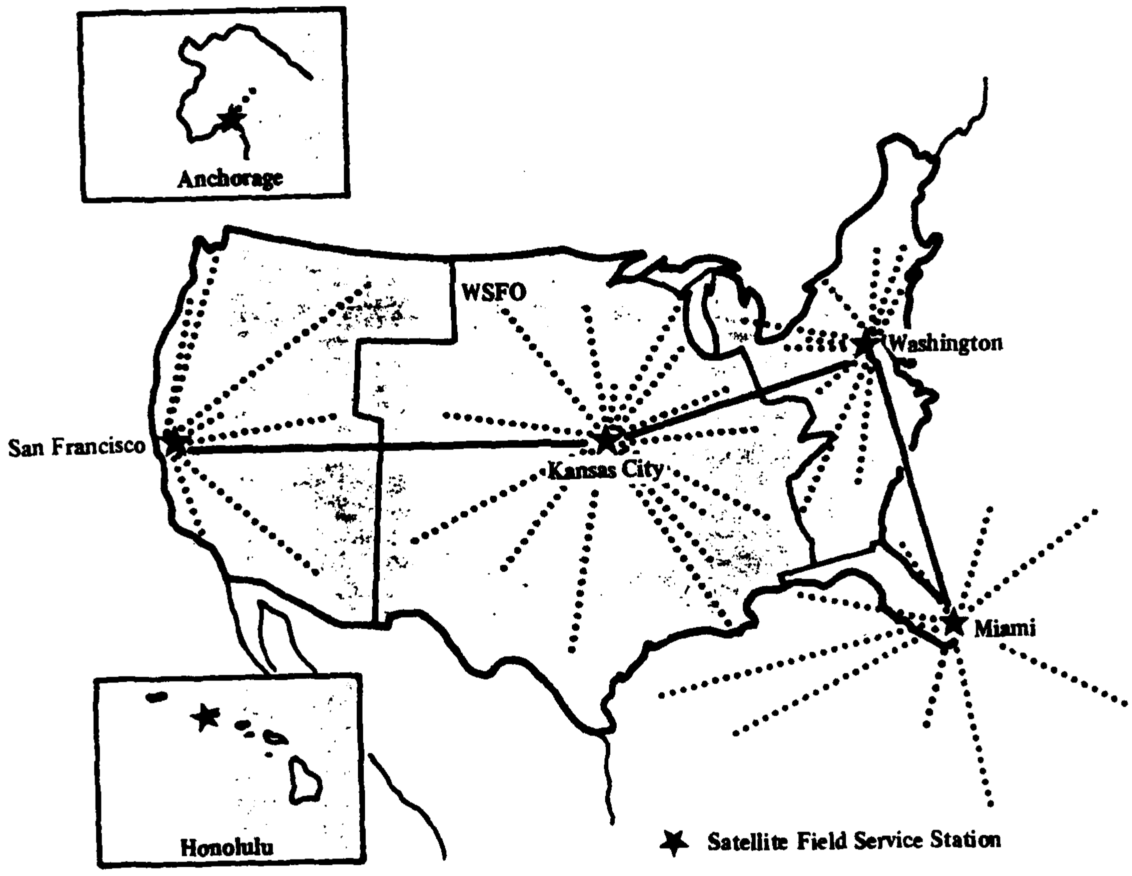
GOES DATA FLOW

SFSS Data Distribution

Satellite Field Service Stations (SFSSs) are located to provide regional service to weather service forecast offices (WSFOs). The SFSS receives both routine and special-request visible and IR images from the CDDF and passes them to the WSFOs.

The WSFOs are the regional forecast units of the National Weather Service. These offices, which serve as points of redistribution to the public, use GOES images to prepare local forecasts.

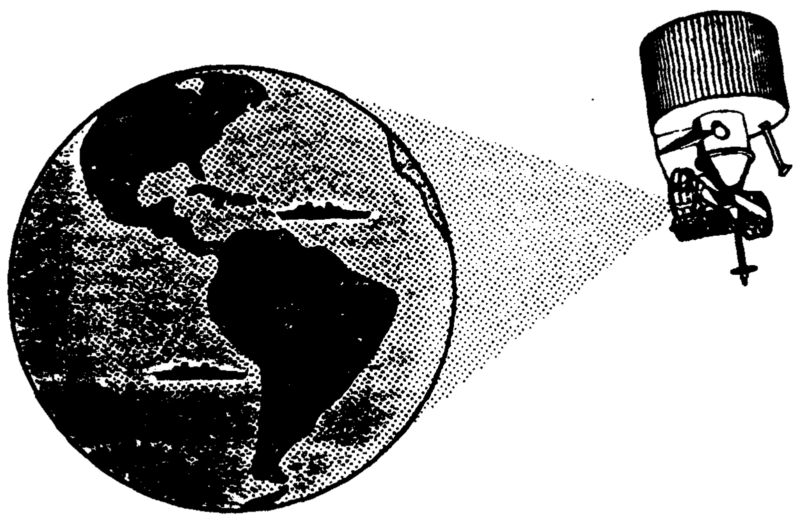
Public interests can access the GOES imagery from the CDDF, SFSS, and WSFO through commercial communications systems. This service is commonly called GOES TAP.



CDDF RELATION WITH OPERATIONAL FIELD USERS

WEFAX

Weather Facsimile (WEFAX) is a communications service provided through GOES. Transmissions are made on S band frequencies (1691.0 MHz). Broadcasts are scheduled in the 10 minute time interval between successive VAS-VISSR mode readouts. The WEFAX product line consists of meteorological charts and imagery from GOES and polar orbiting satellites. GOES VISSR images presented in the WEFAX format have a geometric resolution of 8 km. WEFAX images from TIROS-N are presented with 8 to 12 km resolution in the WEFAX format. Images are transmitted in sections or chips, to be compatible with the WEFAX ground hardware format. Since each chip requires about 4 minutes to transmit, two chips may be contained in each 10 minute WEFAX broadcast interval. One of the WEFAX images contains the daily operational message which provides users with a schedule and identification of the WEFAX transmission content.



WEFAX FORMAT PARAMETERS

Subcarrier frequency	2400 Hz
Subcarrier modulation	AM, 80% max
Start tone	300 Hz for 3 sec
Phasing	12.5 ms, beginning of each line for first 20 lines
Video	800 lines in 200 sec (250 ms per line, including white pulse)
Synchronization or white (blanking) pulse	12.5 ms pulse, beginning of each line of video
Stop tone	450 Hz for 5 sec
Total frame time	213 sec
Interframe gap	20 sec min
Image aspect ratio (height to width)	1:1
Index of cooperation	269

Data Collection System

The Data Collection System (DCS) is used to collect environmental data from any location in the western hemisphere within the field of coverage of GOES East or West. Each GOES satellite serves as a communications relay device between remotely located data collection platforms (DCPs) and a centralized signal acquisition site – the Command and Data Acquisition (CDA) station located at Wallops Island, Virginia.

Approximately 1200 DCPs, owned by a variety of users, are currently serviced by the DCS on GOES East and West. Each DCP transmits its data to a GOES satellite. Data from all the DCPs are collected at the CDA and transferred in real time to the Central Data Distribution Facility (CDDF) located at the World Weather Building, Marlow Heights, Maryland. At the CDDF, data are sorted and returned to the user through conventional telephone lines. Users that have either a low volume of data or data that are not highly perishable can use a 300/110 or 1200 baud dial-up service to receive their data. Large volume users can receive their data on dedicated circuits with a transmission capacity of up to 9600 baud. DCPs are available from a number of commercial sources. Each DCP can be interfaced to a wide variety of environmental instruments.

Three types of DCPs can be accommodated by the DCS:

- Self-timed: DCP transmits data at predetermined fixed time(s)
- Interrogated: DCP transmits data after an interrogation signal is relayed via GOES to the DCP
- Emergency: DCP initiates a signal to GOES requesting that it be interrogated within 1 minute

The self-timed DCP is used when data are needed as a function of time, i.e., when measurements or messages are needed at fixed time intervals or specific times during the day. Collection of pressure, temperature, and humidity measurements for the synoptic times of 00Z, 06Z, 12Z, and 18Z is an example of the use of a self-timed DCP.

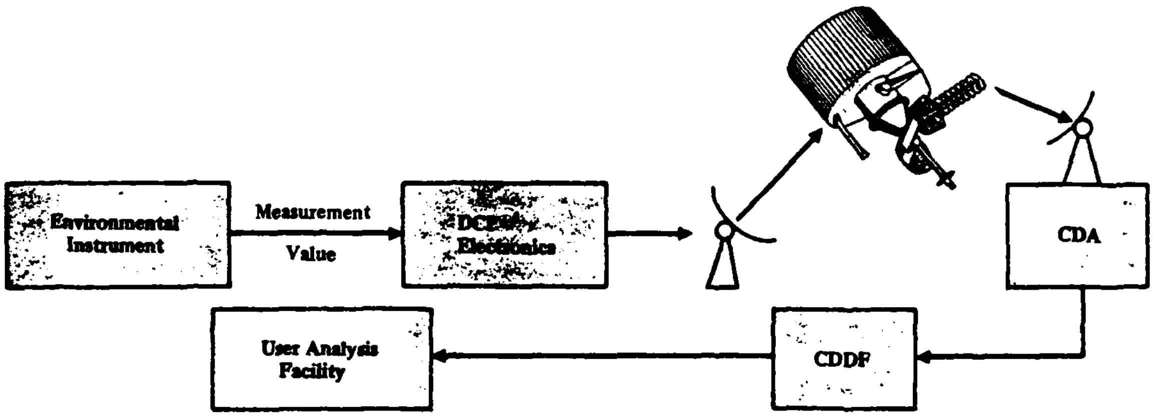
An interrogated DCP is used when data are needed on demand, at nonpredictable time periods, or at continually varying times.

The emergency DCP is used when a sensor measurement reaches a predetermined (i.e., threshold) value indicating a significant event that must be reported immediately. Examples for the application of an emergency DCP include: severe rainfall runoff thresholds at high mountain elevations indicating possible flash flood conditions near the mountain base; tidal wave detection; and high river levels indicating possible flooding.

Services available from the DCS are ideally suited for occasional or repeated environmental measurements from locations that are difficult, hazardous, or expensive to access frequently and/or locations that are not served by existing ground communication networks. For example:

- River level data collected by DCPs are used in flood control management for reservoirs.
- DCPs located in heavy rainfall areas detect the level of runoff. High runoff levels that could present flood threats are transmitted through the DCS and used to invoke emergency warning and/or action procedures.
- Ocean surface and sea-to-air interaction data, collected from buoys in the Gulfs of Mexico and Alaska and the Atlantic Ocean, are used for meteorological and oceanographic analyses.
- Visible and thermal radiation data and ambient air temperatures are used as ground truth information that is correlated with remotely sensed measurements made by instruments carried on satellites such as GOES and TIROS.
- Soil moisture measurements are used to generate daily fire index values in California.
- Michigan State University collects surface data in prime grain growing regions and applies these data to pest control management.
- Data from tide gauges and seismological instruments are used to monitor activities for the Tsunami Warning System.
- Some commercial airliners on transcontinental and transoceanic routes collect upper air measurements and use the DCS for timely delivery of these perishable data to meteorological analysis centers.

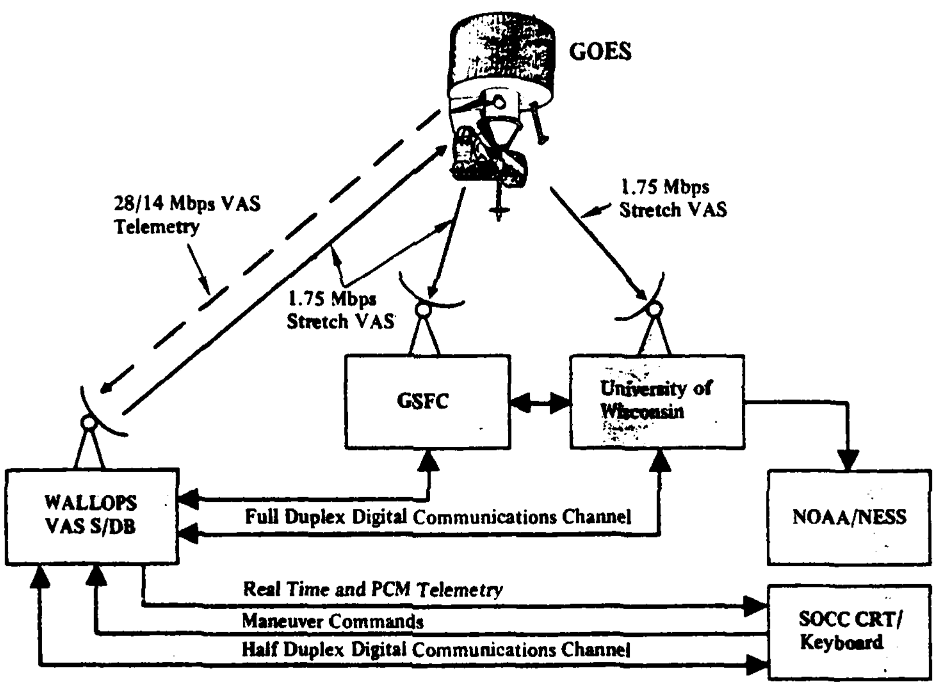
DCP INSTALLED IN SHELTER

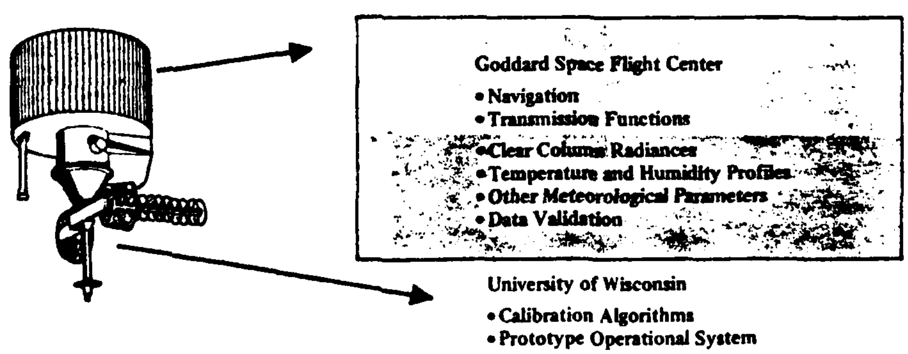


VAS Demonstration

The VAS extends the GOES VISSR capability by including additional spectral bands for collecting data to determine atmospheric temperature profiles and water vapor content. The objectives of the demonstration are to develop use of the MSI and dwell sounding (DS) data, to develop prototype processing algorithms which may be adopted for operational use, and to determine the usefulness of these data in analysis of severe weather situations.

National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), through GSFC and the University of Wisconsin (UW), are the primary participants in the VAS demonstration. They intend to produce a capability to transform satellite raw data in the form of radiances into meteorological parameters which will be useful for analysis and advanced meteorological research. GSFC is working on a research oriented system to evaluate system performance and to experiment with parameter extraction techniques. The UW group is developing a prototype system to provide a real time analysis capability. They are also evolving analysis programs to readily assimilate VAS data with conventional weather data to produce a detailed four dimensional description of the atmosphere for mesoscale phenomena. Techniques are being studied to determine the most effective way of providing timely data sets for meteorological analysis and model initialization for regional scale numerical forecasts. Data sets from the VAS demonstration will be archived. These data will be available to other research institutions and individual scientists.





APPENDIX D
METEOSAT (Europe)

The information in this appendix was taken from the METEOSAT Meteorological Users' Handbook, 15 Nov 1977 and METEOSAT Programme Guide MG/2332 ed. 1, April 1977, both issued by ESA, Earth Observation Program Office. The data contained herein are basically correct, but should be confirmed by ESA before being used, since changes in METEOSAT operations have been made since 1977.

CONTENTS

FIGURES

1. The Satellite System

METEOSAT is a spin stabilized spacecraft in geostationary orbit close to 0° longitude with a nominal spin rate of 100 rpm. The dimensions are:

Height	:	3975 mm
Diamter	:	2100 mm
Weight at start of life	:	293 kg
Weight at end of life	:	245kg

The flow of data between the components is briefly illustrated in Figure D.1. They are listed in the following subsections and their purpose in relation to the missions is described.

1.1 Radiometer

The three-channel, high resolution radiometer constitutes the main payload on board the satellite. It provides radiance measurements in the following wavelengths:

0.4-1.1 micron : 2 visible sensors

5.7-7.1 micron : 1 infrared sensor (in time sharing with one of the visible channels)

10.5-12.5 micron: 2 infrared sensors (one redundant)

The visible detectors are Silicon PIN photodiodes. Each channel consists of a preamplifier, filter, gain control and combined d.c. restoration and output stage. The IR detectors are of the Mercury Cadmium Telluride type. Each IR channel consists of a preamplifier, offset compensation, gain control, d.c. restoration, and filtering.

Typical response curves of the detectors are given in Figures D-2, D-3, and D-4. Figures D-5 and D-6 show the radiometer and the path of incoming light. The radiometer optical system consists of:

- a movable Ritchey - Chrétien type telescope with a primary and a secondary mirror;
- a mirror located in the centre of the primary mirror and inclined 45° to the optical axis of the telescope. The mirror, called the first folding mirror, is mounted in such a way that the emerging light coincides with the telescope pivot axis, thus allowing the remaining mirrors in the light path to be fixed to the non-movable radiometer structure;
- a second folding mirror;
- a refocusing mirror mounted at the extremity of a translation screw, with which refocusing can be performed by telecommand;

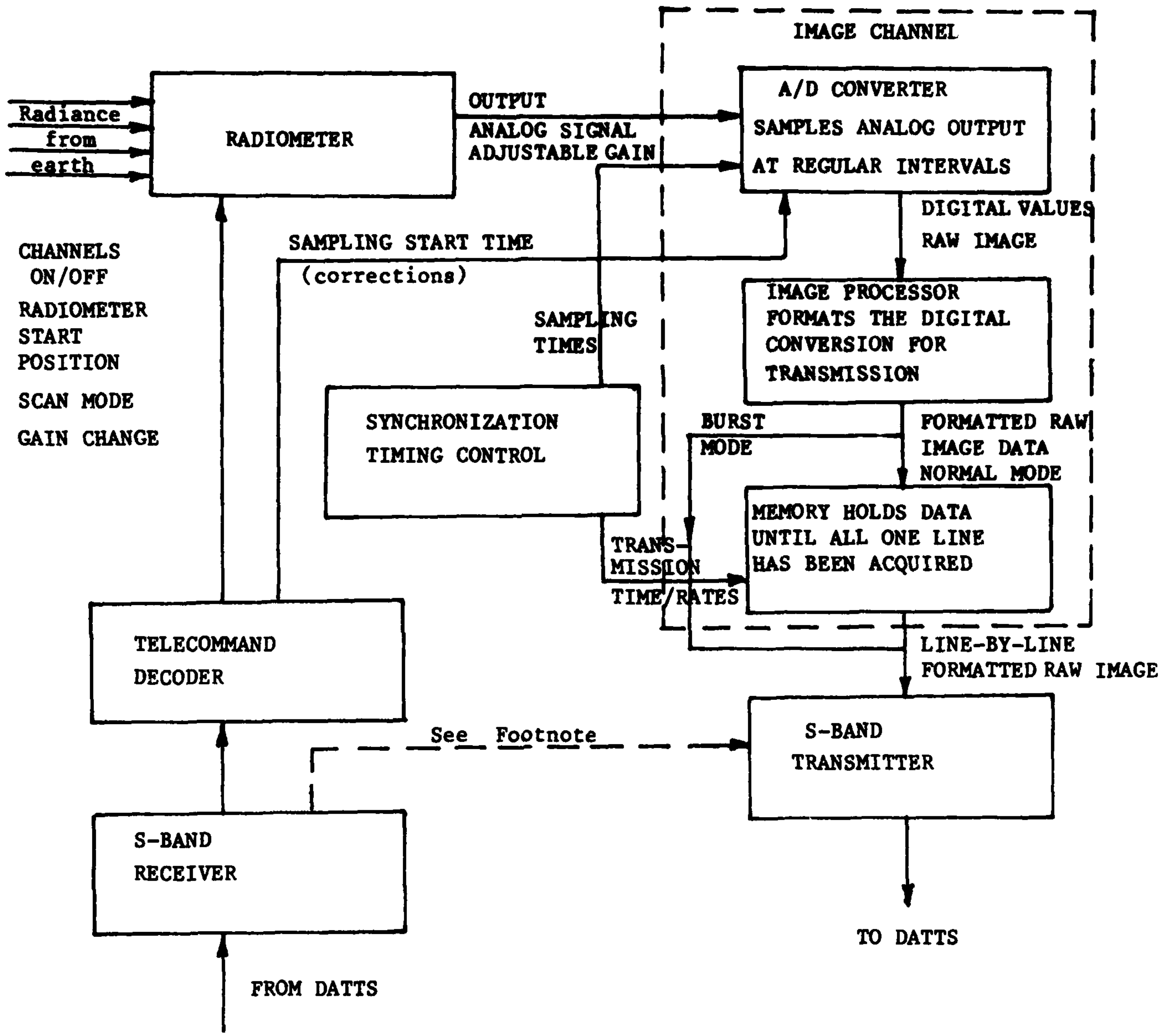


Figure D-1. Flow of information regarding acquisition of radiometric data.

Footnote: This diagram does not show the components of flow connected with Ranging, Dissemination, or DCP.

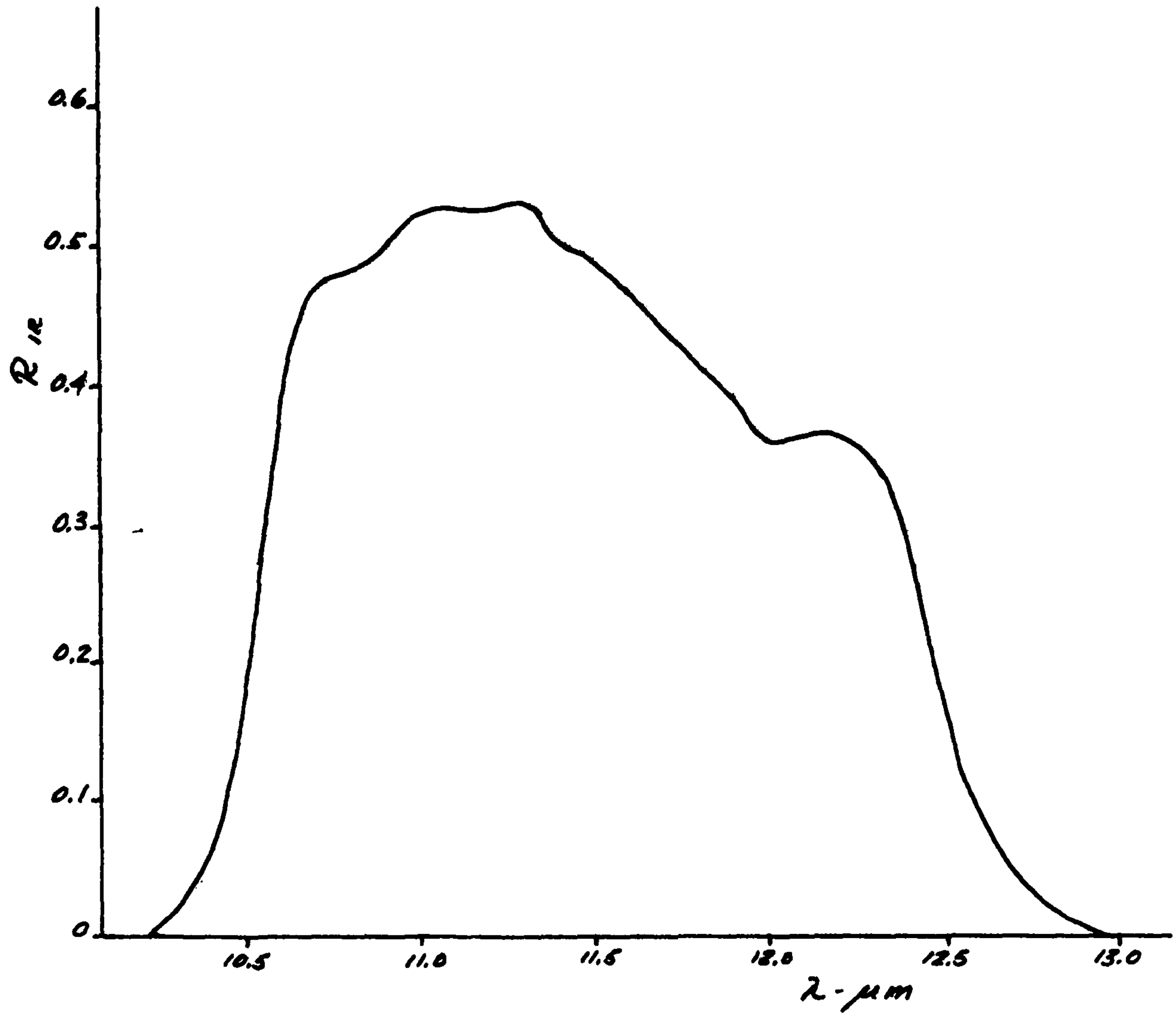


Figure D-2. Spectral Response of a Typical IR Sensor

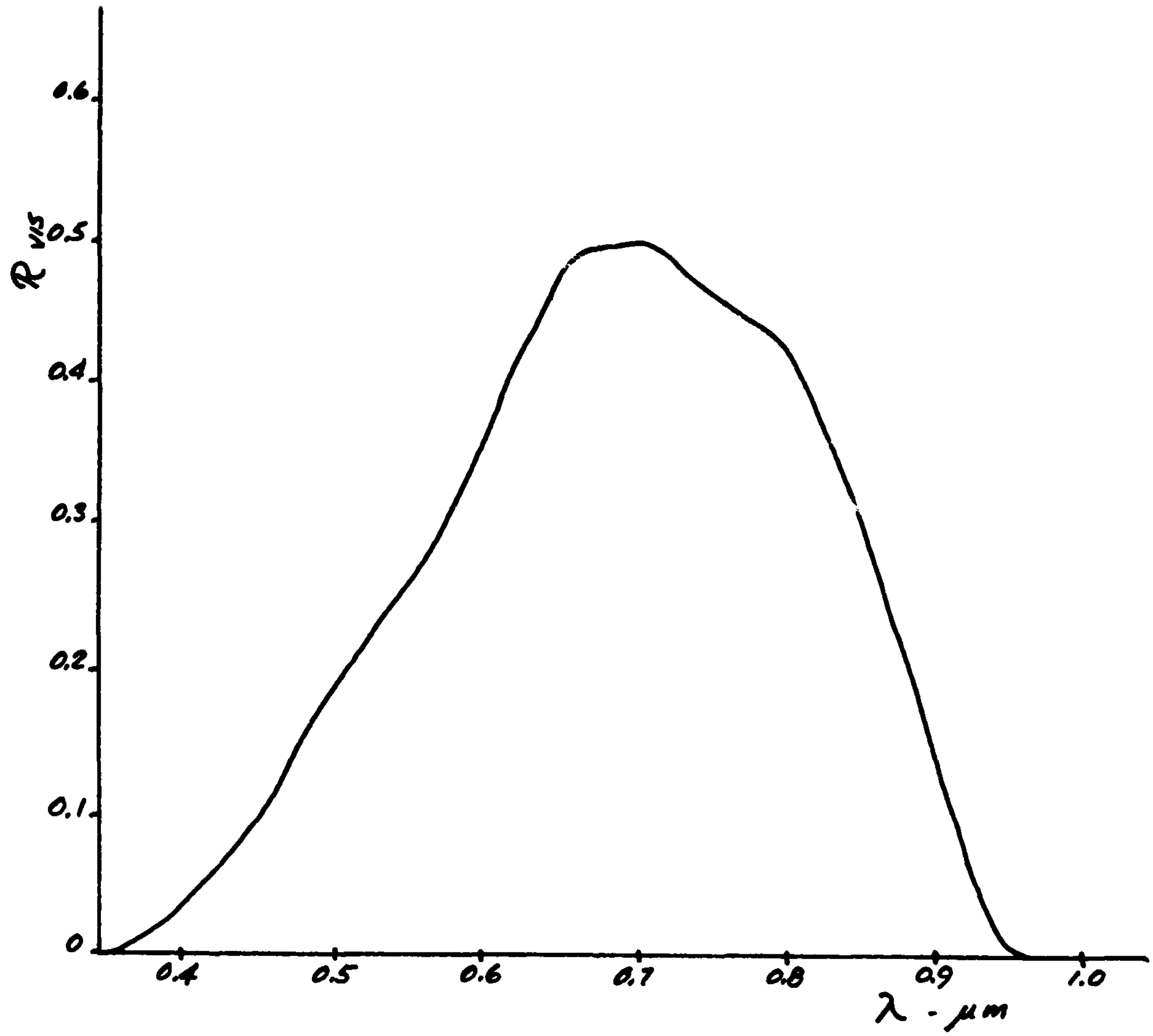


Figure D-3. Spectral Response of a Typical Visible Sensor.

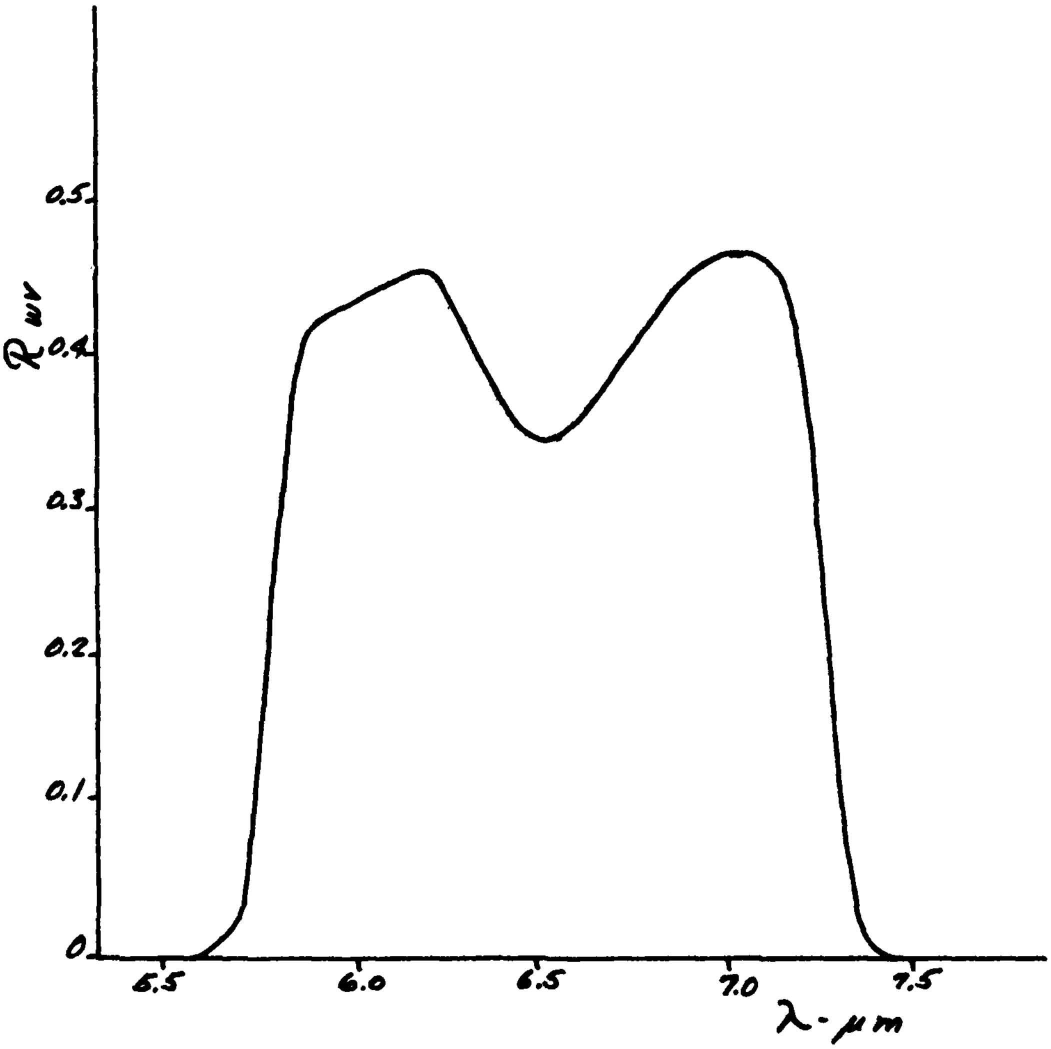


Figure D-4. Spectral Response of the WV Sensor

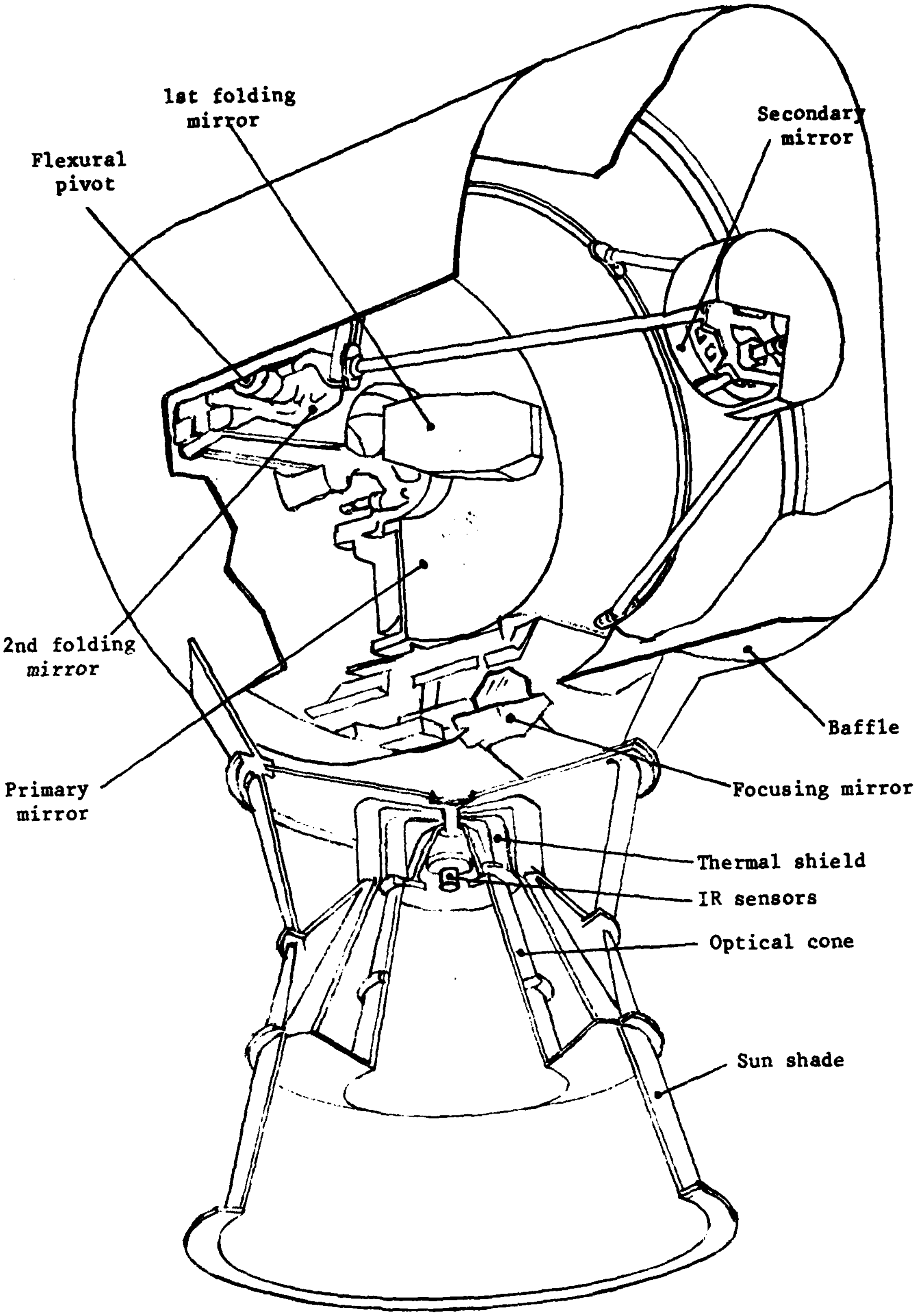


Figure D-5. Radiometer Layout

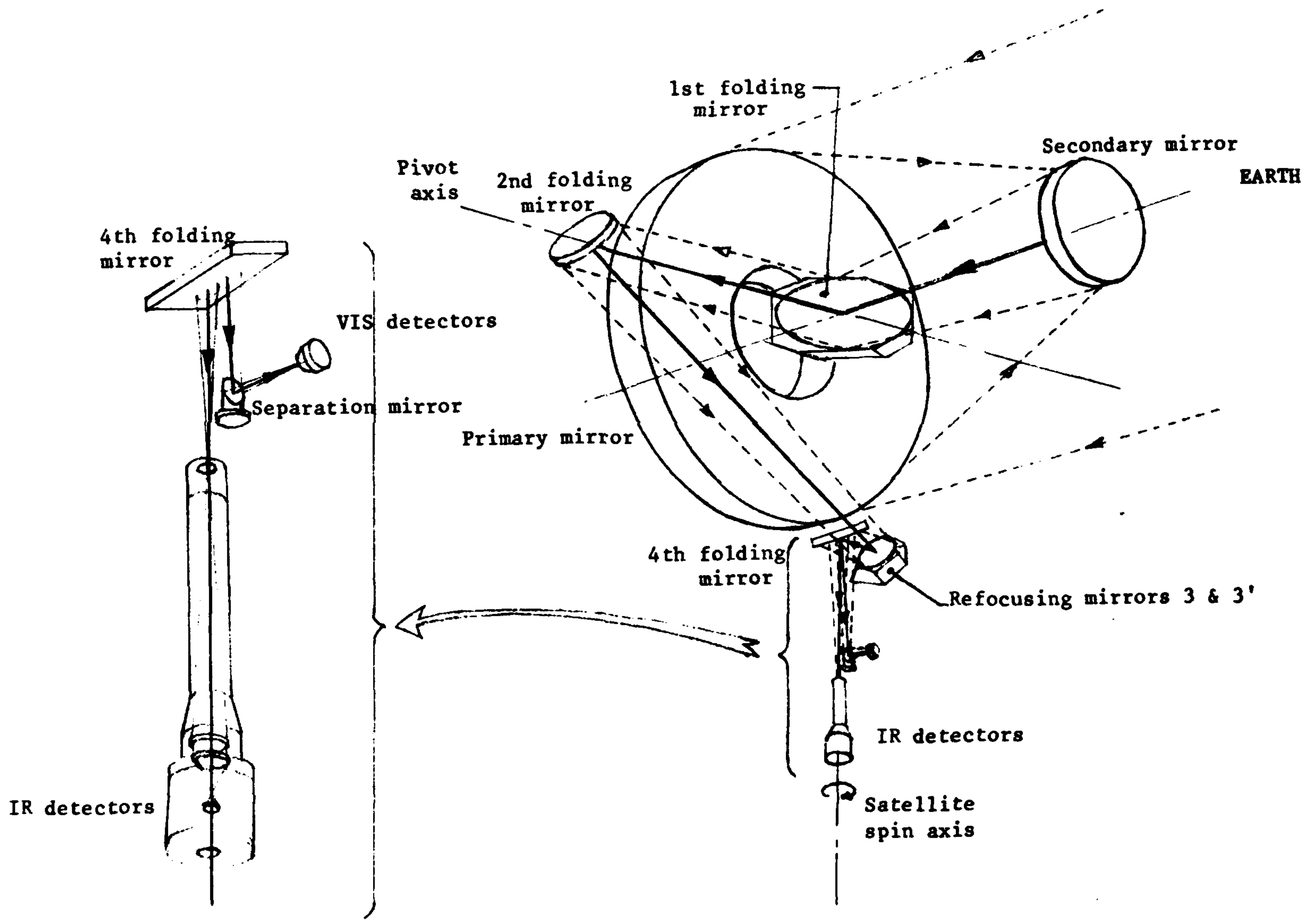


Figure D-6. Separation of Light.

- a fourth folding mirror;
- a separation mirror for diverting light to the VIS sensor.

The telescope is mounted on two flexible plate pivots. The scanning mechanism is a high precision jack screw driven by a step motor via a gear box. At each satellite rotation the spin clock delivers a signal to the motor-driven electronics, whereby the telescope is rotated 1.25×10^{-4} rad. Complete earth scan is thus achieved by this combination of satellite spinning and stepwise tilting of the telescope.

The output from each detector is an analog signal, the voltage of which varies linearly with the incidence radiance. The slope of this linear relation can be adjusted (gain change) in 16 steps so that the range of permissible voltage covers the min./max. radiance.

1.2 Image Channel

The image channel samples the radiometer output and formats the data for transmission. It consists of three major components:

(i) An A/D Converter which samples the analog signals from the radiometer at regular intervals and converts into digital format

(ii) An Image Processor which formats the digital conversion and adds to each line certain auxiliary data (line sync, line ID, datation and radiometer telescope position)

(iii) A Memory. In normal mode, the output of the image processor is stored in memory and retransmitted in a stretched mode to the ground. That is, the data is acquired in the memory in 0.03 seconds while the radiometer telescope is sweeping across the earth's disc and is read out and transmitted to the ground (at a slower rate) in the following 0.48 seconds (approximately). In burst mode, when the Memory fails, the output of the image processor is transmitted in real-time (at the acquisition rate).

1.3 Synchronization

The synchronization unit or spin clock ensures proper timing of the radiometer and satellite image channel. All on-board timing is derived from a centralized oscillator operating at 5.333 MHz.

1.4 Other major components

TC Decoder	- This decodes the TC messages and distributes them to the proper units (or stores time tagged commands until the proper execution time). For imagery, the various detectors can be switched on/off, various types of scan mode initiated, calibration constants set, focusing carried out, etc.

S-Band Transmitter and Receiver - For transmitting the raw image as formatted by the satellite image processor to the ground; for receiving telecommands for transmitting Housekeeping Data (H/K) ranging signals and transmitting processed image data received from the ground processing centre to users' stations.

2. The Ground System

Figure D-7 summarizes the ground system and Figure D-8 gives the layout of the METEOSAT Ground Computing System.

The ground system consists of the data acquisition, telecommand and tracking station (DATTS) connected by a dedicated line to the METEOSAT ground computer system (MGCS). For tracking purposes, a land-based transponder is located in KOURU (French Guyana). Backup communication with the satellite using VHF is available from REDU (Belgium). The relay of data between DATTS and MGCS and between REDU and MGCS is undertaken by the Data Transmission and Routing System (DTRS). For a detailed escription of DATTS and DTRS reference should be made to the Ground Segment Handbook, Chapter 4. The MGCS is also connected by a dedicated line to the Regional Telecommunication Hub (RTH) at Offenbach.

The meteorological user is not concerned with the functioning of DATTS or DTRS. The receipt or transmission of image data is not affected except that the following points should be noted:

- The DATTS can store up to 1 second of incoming image data (that is, about 1½ lines) in case of a short break in the link DATTS-MGCS, and can then catch up by transmitting the next 5 lines at a higher rate. The consequence of this is that the image acceptance and preprocessing tasks in the MGCS must be data driven and the system cannot detect a missing line until the next real line arrives.
- DATTS writes at the beginning of each line before transmitting to the MGCS the time of receipt of the SYNC word of that line in DATTS.
- In burst mode DATTS stores each data line and transmits it to the MGCS at the normal rate. This means that the image acceptance task is the same whether the satellite is transmitting the image data in burst or normal mode, except that the expected time of receipt of the SYNC word will be different.

The DTRS routes the various messages from DATTS to the correct computers in the MGCS as follows:

- Image data to the two S-330 labelled "Front-end processors" (FEP) in parallel;

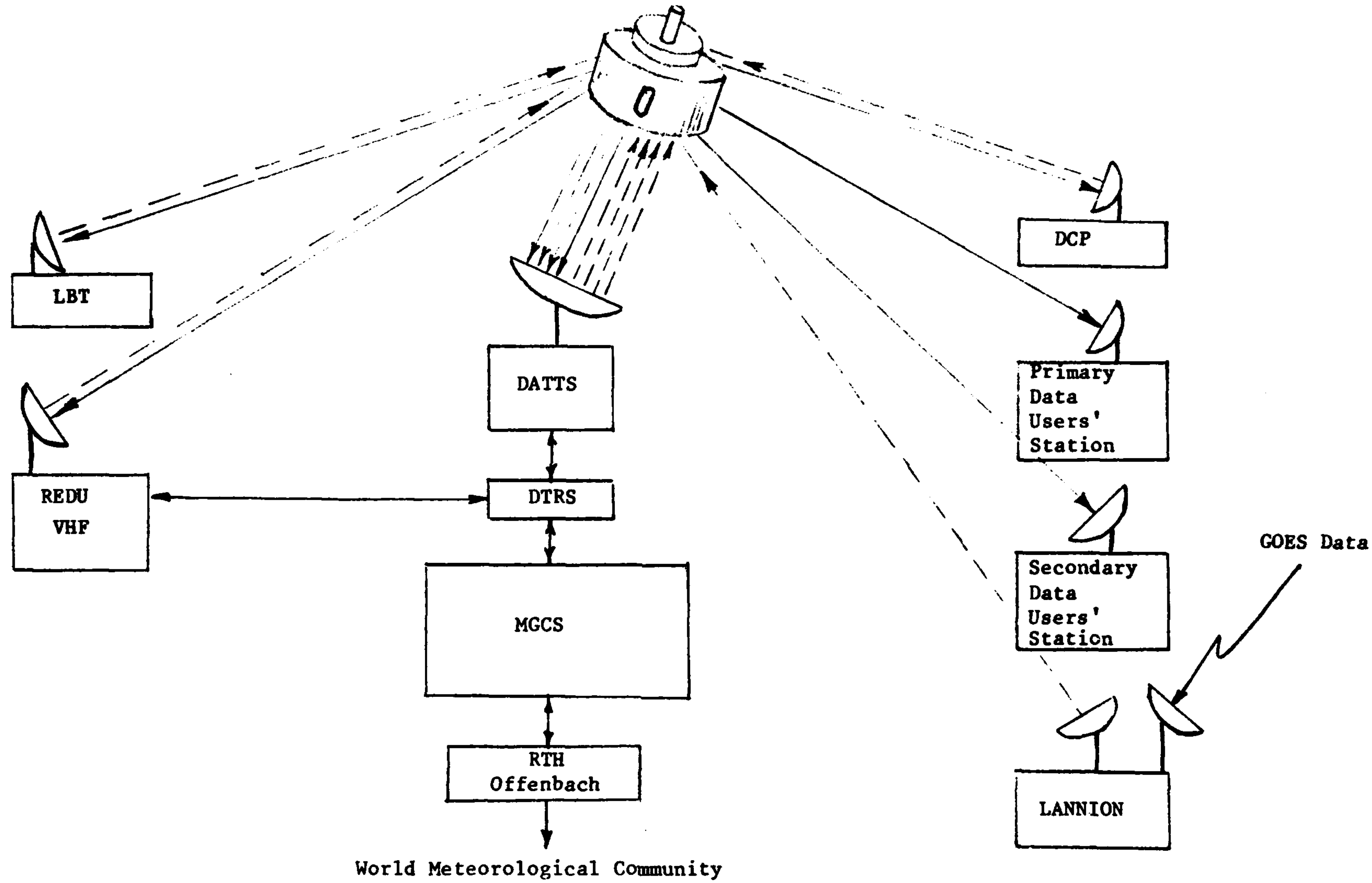


Figure D-7. METEOSAT Ground System

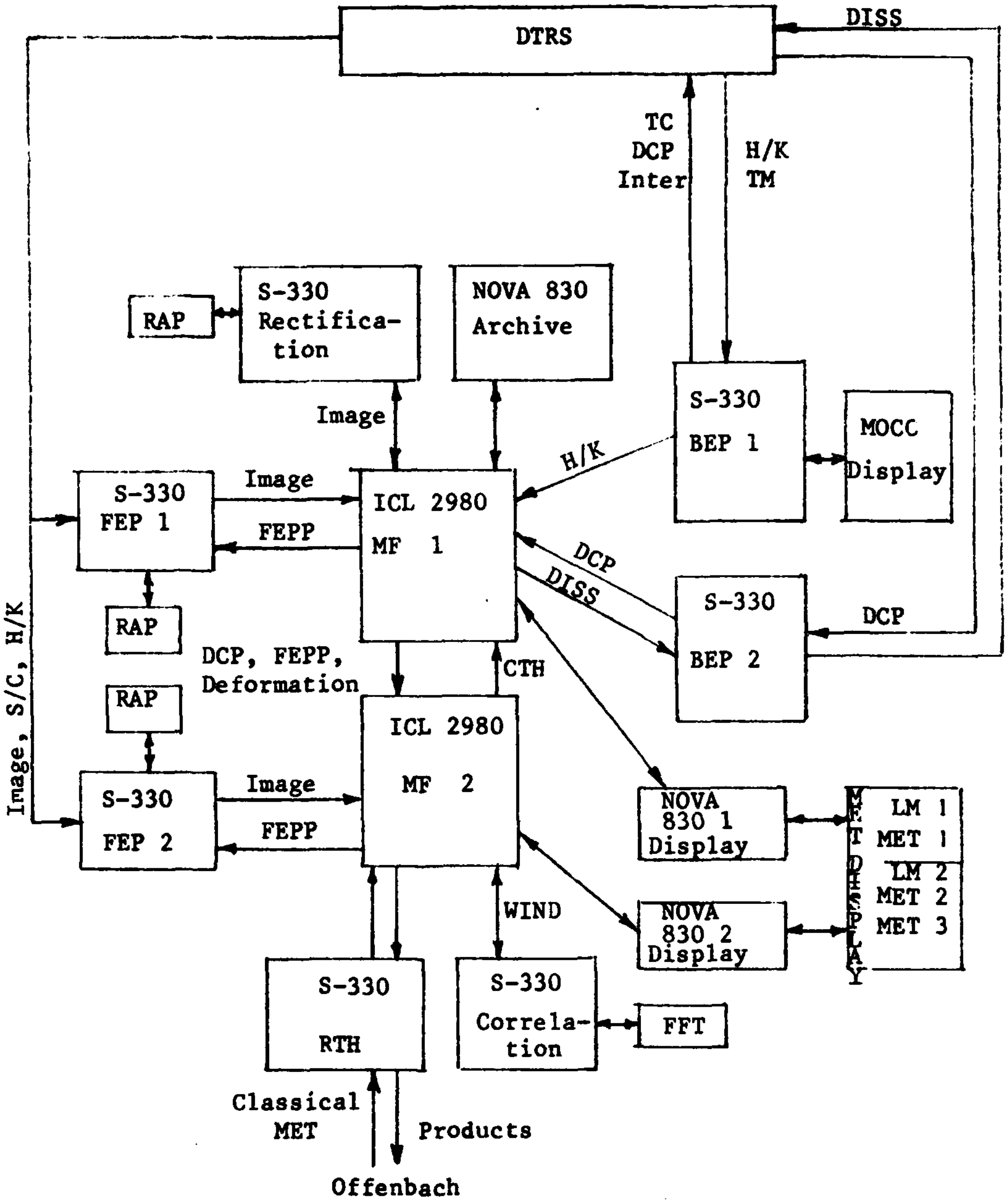


Figure D-8. MGCS Nominal Operational Configuration (Software Concept)

Note: All minis switchable to either mainframe.
All displays switchable to either supporting mini.

- H/K and telemetry data to the two S-330 labelled "Back-end processors" (BEP), although in normal mode only BEP 1 will process this data;
- DCP data to the two S-330 labelled BEP, although in normal mode only BEP 2 will process this data.

Data for dissemination via the satellite are passed by the DTRS to the DATTS from BEP 2; telecommands and DCP interrogations from BEP 1. Data for dissemination via the RTH to the world meteorological community through the Global Telecommunications System (GTS) are passed through the S-330 labelled RTH via landline to Offenbach.

The image data is preprocessed by the two FEP in parallel and the preprocessed data is passed simultaneously to two ICL 2980 mainframes (MF). In the event of one MF failure, the FEP that was connected writes the output to a tape. In the event of both mainframes failing this tape ensures that no image data is lost. However, the problem of transforming the data on this disk into the normal form in which image data is archived has yet to be solved.

In normal mode MF 1 handles the image referencing task, the dissemination formatting, archive preparation, DCP processing, and other tasks such as orbit computation associated with spacecraft control. It is connected to both BEP and to the archive NOVA computer. Dissemination via the satellite and DCP reports are handled through BEP 2; all other tasks through BEP 1. The image referencing task prepares parameters which are required by the FEP. Also other parameters (such as radiometer sensors on/off) are passed by MF from BEP 1 to FEP, the communication between MF 1 and FEP 2 being via MF 2.

MF 2 handles the meteorological extraction tasks and also dissemination to the RTH. The S-330s dedicated to rectification and correlation are connected to MF 1 and 2 respectively.

All mini computers can be connected to either mainframe, but only by manual switching. Permanent links which can be activated automatically do not exist.

The interactive system consists of one landmark console and one MIEC console connected to NOVA 1 (which is normally connected to MF 1) and one landmark console and two MIEC consoles connected to NOVA 2 (which is normally connected to MF 2). The NOVA and the consoles are all individually switchable. The mission control consoles are connected to BEP 1.

There is a link connecting BEP 1 and BEP 2 but otherwise mini computers are not interconnected.

3. WEFAX Image Dissemination

The images disseminated are from two different sources:

The main source is Meteosat itself and its radiometer, which takes picture of earth from its geosynchronous equatorial orbit at an altitude of 36,000 km at 0^{o} longitude.

The second source is the American satellite, GOES-1, which carries out a similar mission over the American continent at a longitude of 75^{o} West.

3.1 Meteosat images

They are transmitted, after sectorisation, with their full geometrical resolution.

3.1.1 Visible Image

The satellite normally produces one visible image every half hour. This image is comprised of five thousand points per line and five thousand lines. Its resolution at the sub-satellite point is 2.5 km. The information is coded at the origin in 64 levels.

This image is disseminated in the WEFAX format known as Format C, after sectorisation as indicated in Figure D-9.

3.1.2 Infrared and Water Vapor Images

The satellite takes a picture every half hour in the 10 to 12.5 micron band, thus supplying an infrared image. The latter consists of 2500 points per line and 2500 lines, corresponding to a resolution of 5 km at the sub-satellite point. The information is coded at the origin in 256 levels.

The picture in the water vapor channel (5.7 to 7.1 micron band) is taken less frequently. It has the same resolution but is coded at the origin in 64 levels.

These images are disseminated in the WEFAX format known as D or E, depending on whether they are infrared or water vapor images, after sectorisation, as indicated in Figures D-10 and D-11.

3.2 Images from GOES

These are relayed by the "Centre d'Etudes de Météorologie Spatiale" in Lannion (France) and are sectorised and compressed before transmission with the result that they do not have the resolution of the original image.

The Z format visible image and the Y and R format infrared images are described in Figures D-12 and D-13. In the case of GOES-1, there is no image taking in the water vapor channel.

Visual Spectrum

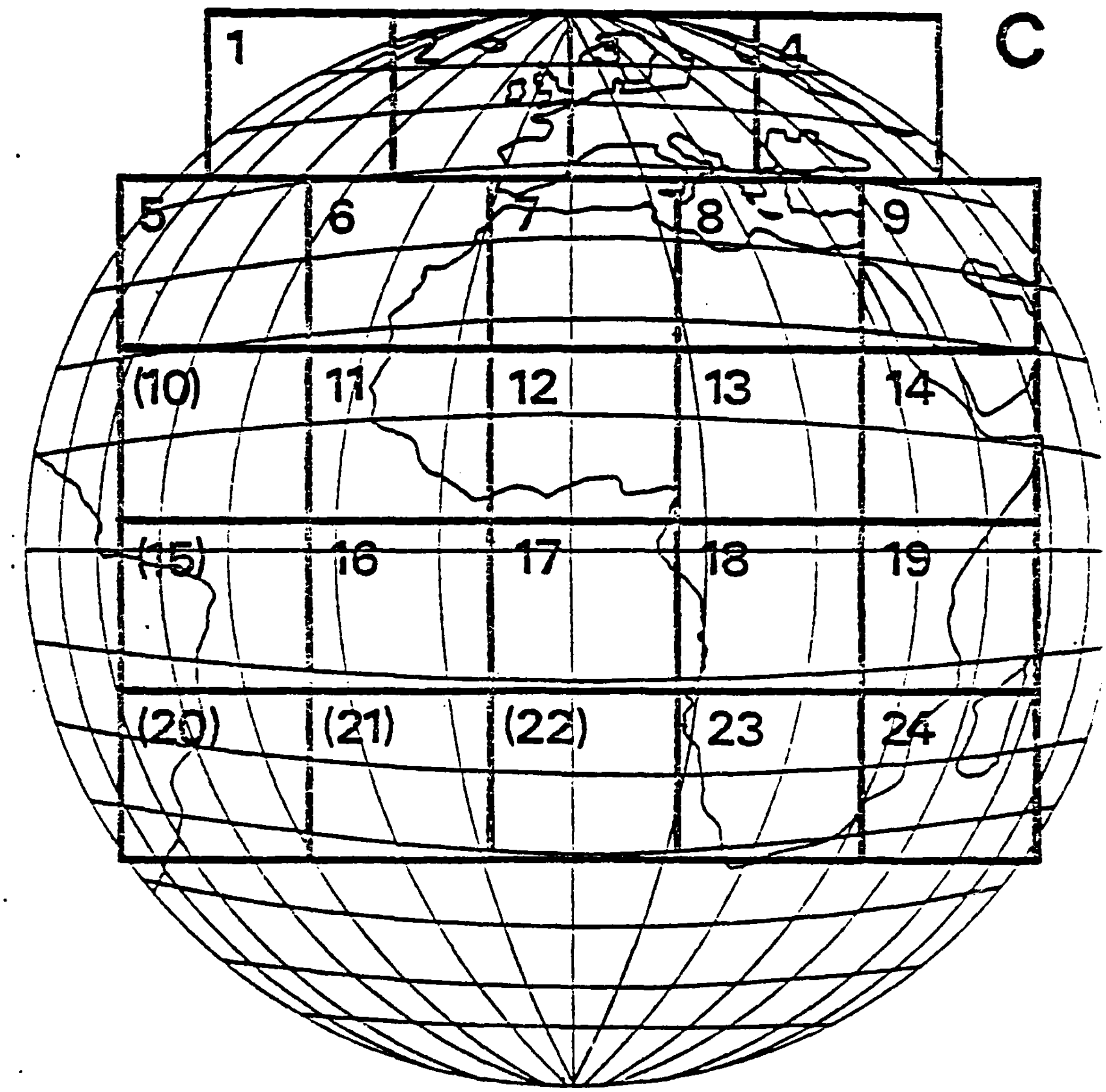


Figure 9. **VISUAL SPECTRUM**

Sector	C1	C2	C3	C4	C5	C6	C7	C8	C9	C11	C12	C13	C14	C16	C17	C18	C19	C23
Frequency (hrs)	3	0.5	0.5	1.5	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	3	3	1.5	1.5	1.5
Duration (min)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

Sectors 10, 15, 20, 21 and 22 are not normally transmitted.

WEFAX SECTOR FORMAT D

Infrared Spectrum

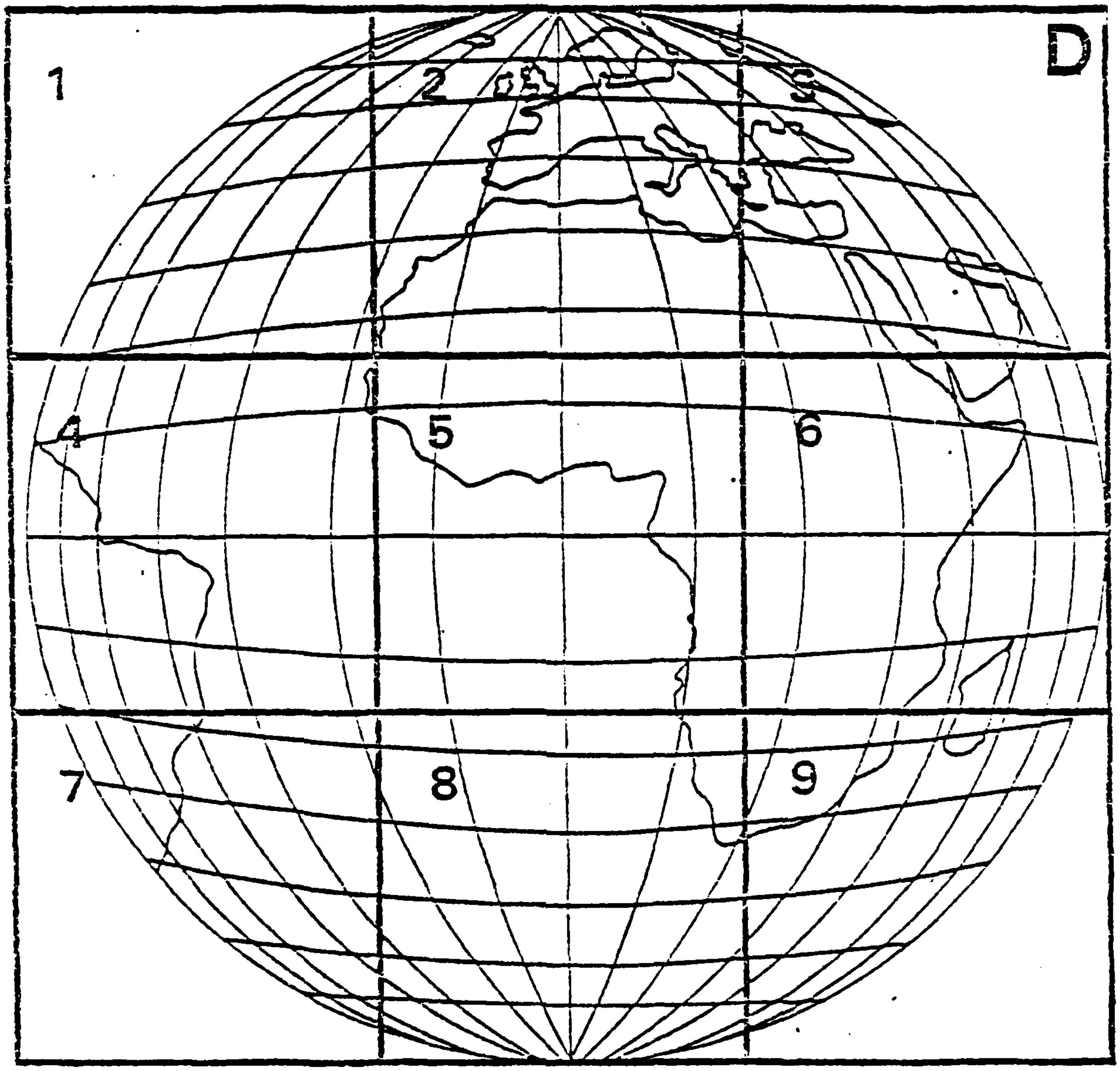


Figure 10. Infrared Spectrum

Sector	D1	D2	D3	D4	D5	D6	D7	D8	D9
Frequency (hrs)	3	0.5	3	3	3	3	3	3	3
Duration (min)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

WEFAX SECTOR FORMAT E

Water Vapour Spectrum -

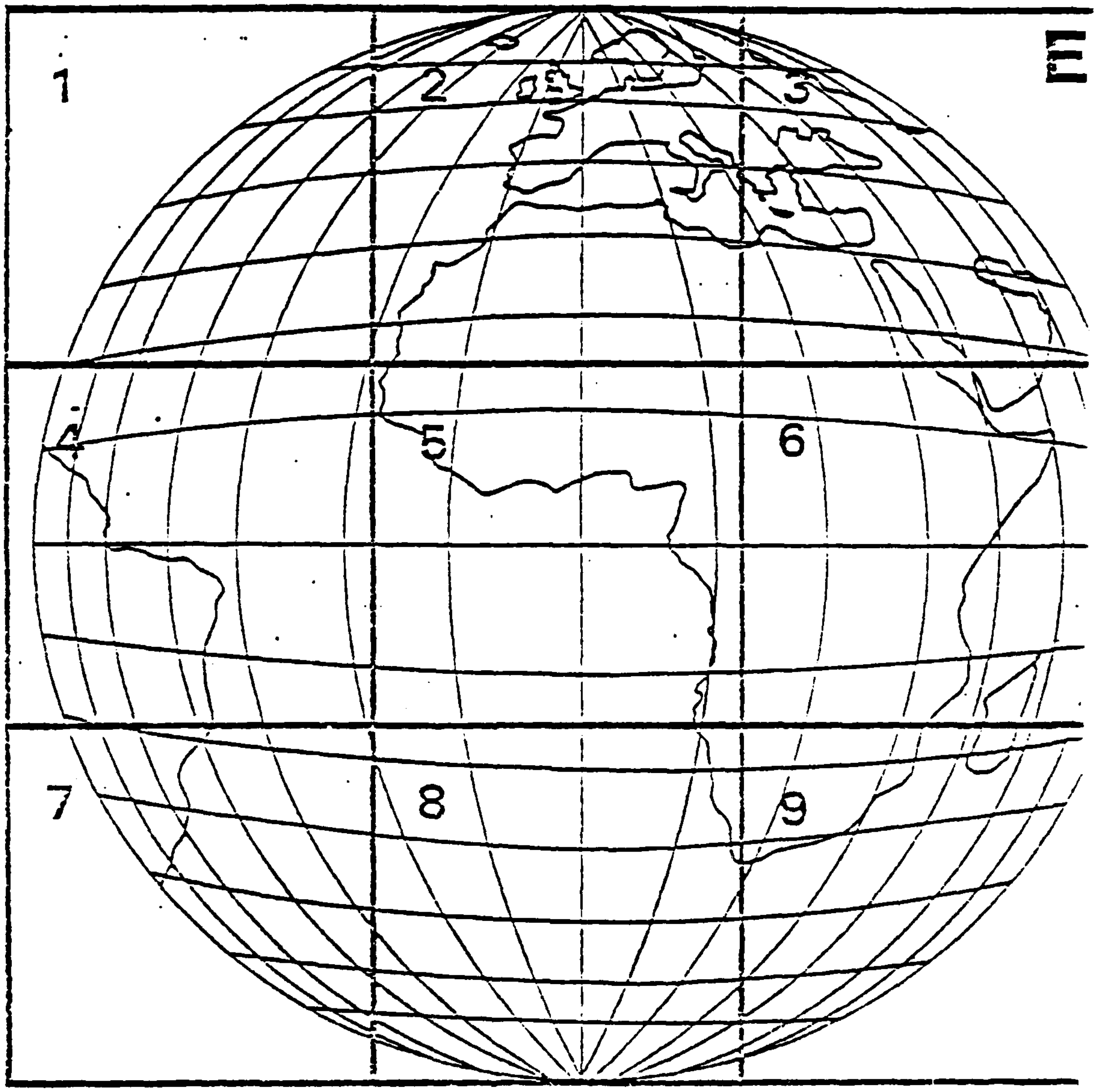


Figure 11. Water Vapour Spectrum

Sector	E1	E2	E3	E4	E5	E6	E7	E8	E9
Frequency (hrs)	6	6	6	6	6	6	6	6	6
Duration (min)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

WEFAX SECTOR FORMAT Y AND R

Infrared Spectrum

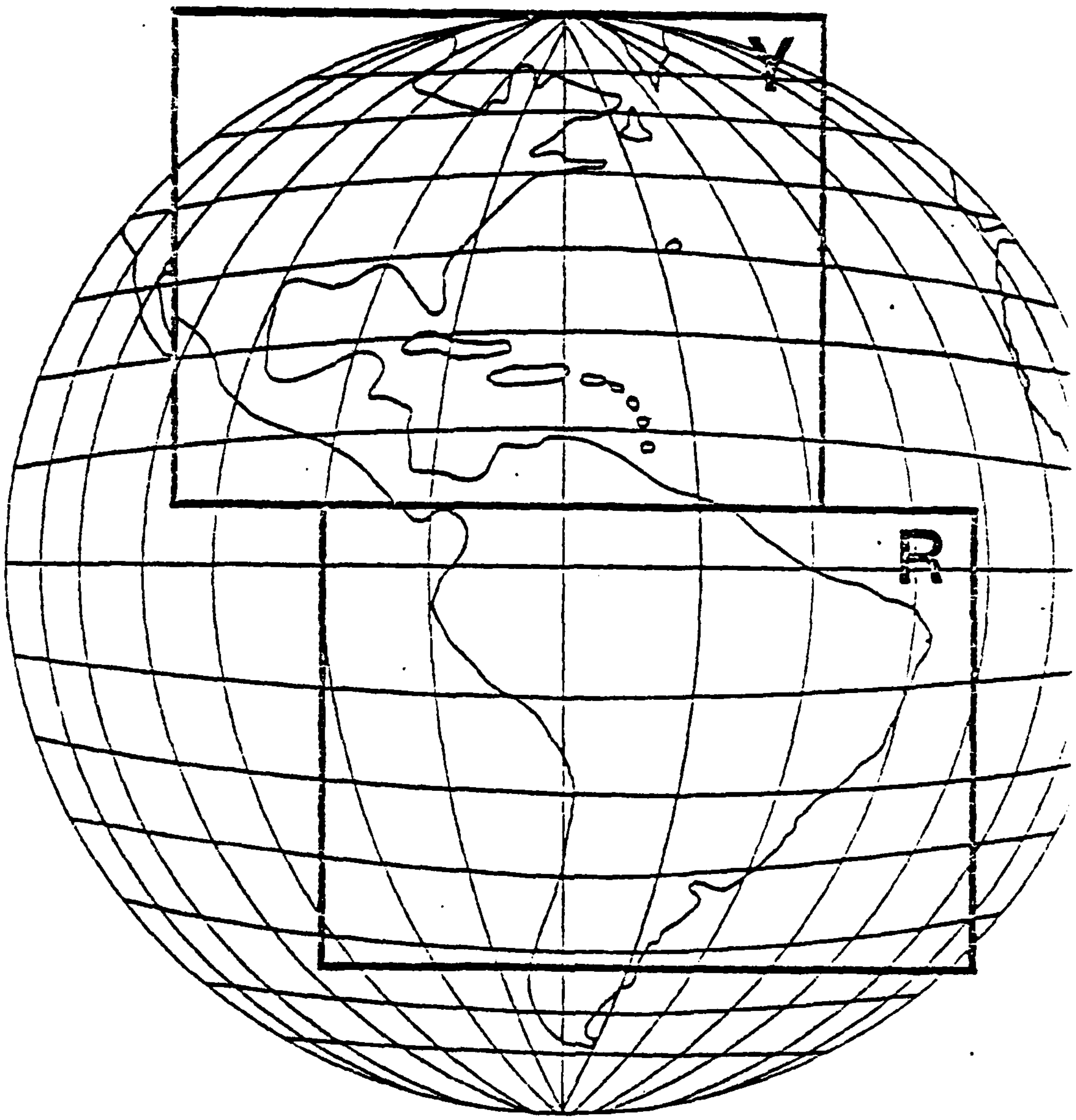


Figure 12. Infrared Spectrum		
Sector	Y	R
Frequency (hrs)	3	12
Duration (min)	3.6	3.6

WEFAX SECTOR FORMAT Z

Visual Spectrum

Figure 13. Visual Spectrum	
Sector	Z
Frequency (hrs)	3
Duration (min)	3.6

3.3 Annotations

These are superimposed on the image and contain:

- The origin of the data (MTO or GOES)
- The date and time of the end of the picture-taking
- The channel used (spectral band)
- The letter and number corresponding to the format transmitted
- A coded text in the form of some letters and figures indicating the quality of the image and the processing that it has undergone:

  J : abnormal jig

  N : abnormal noise

  D : reduced dynamic range

  S : low sensitivity

  Q : abnormal quality of geometrical processing

  0 : raw image

  1 : calibrated image

  2 : like 1, with line deconvolution

  3 : like 2, with vertical registration of the lines

  4 : like 2, with bi-dimensional deconvolution

  7 : rectified image by means of deformation prediction

  8 : image rectified by use of measured deformation with calibration including statistical smoothing

4. WEFAX Transmission Characteristics

4.1 Format of Images

4.1.1 Generation of Meteosat Images

The images are generated at the Darmstadt Processing Centre (DRCC) in digital form and are transferred to the transmitting station where they are converted into analog data before being transmitted to the satellite.

This conversion is carried out at the rate of 3360 points per second, so as to take account of a rate of 240 lines per minute, and 840 points per line (40 margin points followed by 800 useful image points). A 1600 Hz low pass filtering is effected before modulation.

The signal then modulates the sub-carrier, then the carrier for the selected dissemination channel.

4.1. 2 Format of an Image (See Figure D-14)

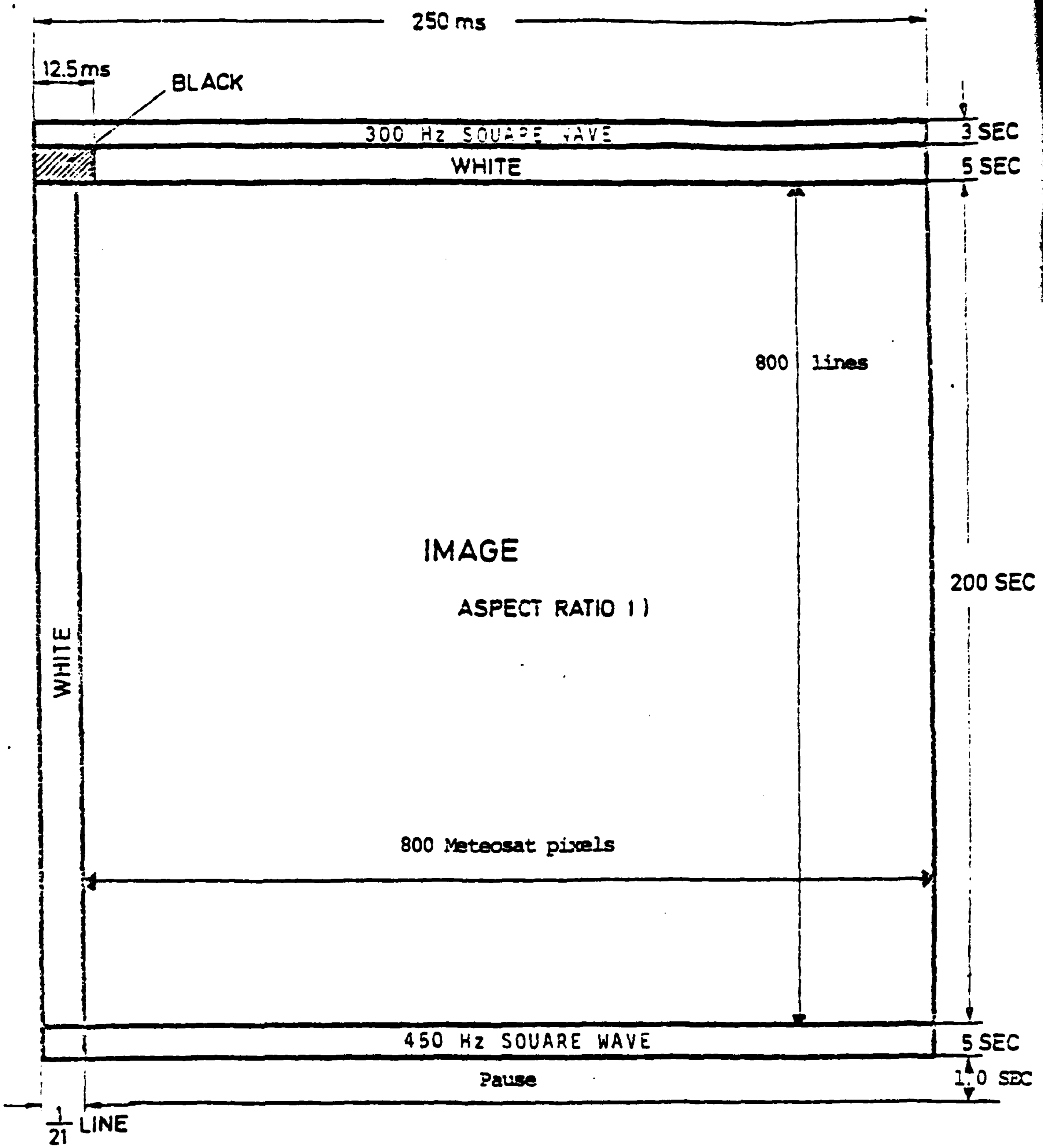


Figure D-14. Format of an Image.

The actual image is preceded by the transmission, for three seconds, of a rectangular wave signal at 300 Hz ± 5 Hz for the supply of current for the facsimile equipment.

The line synchronisation code which follows consists of 20 lines (5 seconds). The "black" level transmitted at the beginning of these lines is maintained for 5% of the duration of the line (12.5 ms).

After this synchronisation code, the 800 lines constituting the image are transmitted. Each of these lines begins with a "white" level of a duration of 1/21st of a line (11.9 ms).

Finally, the transmission for 5 seconds of a rectangular wave "switching off" signal at 45 Hz ± 5 Hz marks the end of the image.

There is a break of 10 seconds between the end of the latter signal and the start of the 300 Hz signal of the following image.

Since the useful image in principle has an aspect ratio of 1:1 because it is square, the index of cooperation (IOC) adapted to the signal transmitted is 267.36. If the IOC of the display equipment used is not adjusted to this figure, the restored image is rectangular, one of its dimensions being considered to be multiplied by the IOC ratio. This is not necessarily an inconvenience.

4.2 Modulation Characteristics

Type of modulation	AM/FM
Peak frequency deviation	9 KHz
Sub-carrier frequency	2400 Hz
Sub-carrier modulation	AM, 80% max = white, min = black
Base band video	1600 Hz
RF band width (Carson's rule)	26 KHz

Thus, the frequency demodulation gain is theoretically 17.5 dB; this is the ratio between:

> The signal-to-noise ratio at the output of an FM demodulator measured in a 0 to 4 KHz band
>
> and the signal-to-noise ratio at the input, measured in a 30 KHz band; these are signal and noise powers (root mean square values).

The overall demodulation gain is expressed as the ratio between:

> the peak-to-peak signal-to-noise ratio at the output of the AM demodulator, measured in a band of 0 to 1600 Hz

and the signal-to-noise ratio at the input, as above. Its theoretical value is 21.2 dB.

4.3 RF Characteristics

	Dissemination channel 1	Dissemination channel 2
Frequency	1691 MHz	1694.5 MHz
Long-term stability 3 years in the worst case (1)	$\pm$ 21 KHz	$\pm$ 21 KHz
Relative short-term stability in the worst case	$\pm$ 7x10^{-9}/sec	$\pm$ 7x10^{-9}/sec
Polarisation	linear	linear
EIRP at Earth's edge	18.8 dBW	19.7 dBW
P/N_o (2)	74.6 dBHz	74.6 dBHz

(1) This stability may prove to be much better

(2) P/N_o is the power-to-noise density ratio at the input of the on-board transponder-receiver; this figure characterises the quality of the dissemination up-link.

The following link budget shows the quality of image that it is possible to obtain with a good quality station at Earth edge with an elevation angle of 10°:

EIRP	dBW	18.8
Propagation attenuation in free space	dB	-189.2
Various propagation losses	dB	-1
Figure of merit of the station (G/T)	dB/K	2.5
Input signal-to-noise ratio in 30 KHz	dB	14.9
Demodulation gain	dB	21.2
Technological demodulation losses	dB	-2
Peak-to-peak image signal to rms noise ratio (0 to 1600 Hz band)	dB	34.1

As a comparison, a signal coding on 16 levels gives a quantisation noise of similar importance.

In addition, it should be noted that this link budget is for an unfavorable case. A station situated near the sub-satellite point has an advantage of about 4 dB due both to better satellite antenna gain at the centre of the beam and to the free space loss, which is reduced.

APPENDIX E

GEOSTATIONARY METEOROLOGICAL SATELLITE (JAPAN)

The information in this appendix was taken from Meteorological Observation from Space by Geostationary Meteorological Satellite (GMS) published by the Japan Meteorological Agency, 1977. Current data formats may differ in detail from those presented here.

CONTENTS

TABLES AND FIGURES

Introduction

Owing to very broad coverage of GMS observations utilization of its products can greatly contribute to improvement of international meteorological services as well as domestic services. Concerned users are encouraged to access to GMS products, and this brochure is provided to help those users.

Reception of Cloud Image Facsimile Transmissions

Three-hourly observations are made on a routine basis. In order to help users to easily access to acquired cloud imageries JMA processed the acquired raw complex signals into simple facsimile forms utilizing very large computer systems.

Facsimile transmissions

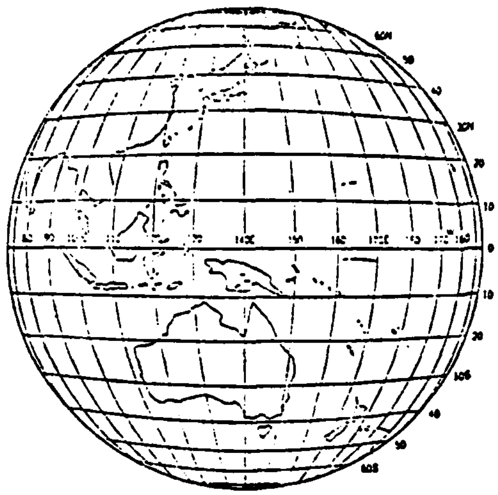
Computer processed imagery signals are retransmitted from a ground station to GMS so that those pictures are broadcast from GMS for reception and utilization by international users. High Resolution Facsimile (HR-FAX) and Low Resolution Facsimile (LR-FAX) are available at Medium-scale Data Utilization Stations (MDUS) and Small-scale Data Utilization Stations (SDUS) respectively.

The HR-FAX is a picture transmission of a full earth disc, while the LR-FAX is of a seven-sectroized full disc. This concept is given in Figure E-1. In consideration of the compatibility with NOAA receiving stations already installed, LR-FAX transmission format is arranged to be close to that of NOAA APT transmissions. The transmission format for HR-FAX is the same as that of US NOAA meteorological satellite VHRR.

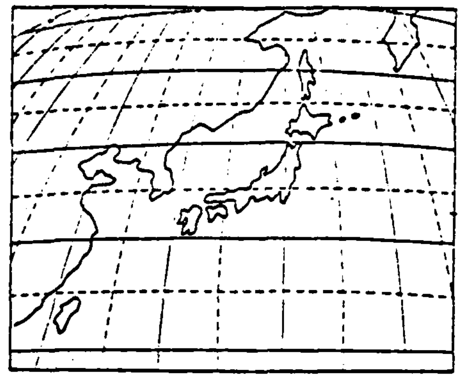
The major transmission parameters are as follow:

Parameters	HR FAX	LR FAX
Spacecraft position	140^{o}E (36000 km above the equator)	
EIRP	54.3 dBm	54.3 dBm
Polarization	Linear	Linear
Frequency/modulation	1687.1 MHz/FM-FM	1691.0 MHz/AM-FM
Main carrier frequency deviation	300 kHz	9 kHz or 123 kHz
Main carrier bandwidth	1 MHz	26 kHz or 260 kHz
Sub-carrier frequency	99 kHz	2.4 kHz
deviation/modulation index	29 kHz	80%
Maximum video frequency	21 kHz	1.68 kHz

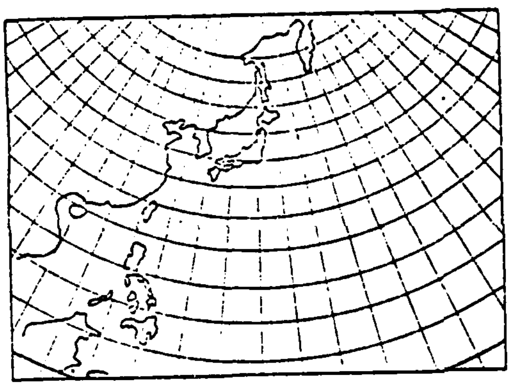
1) Full-disc picture



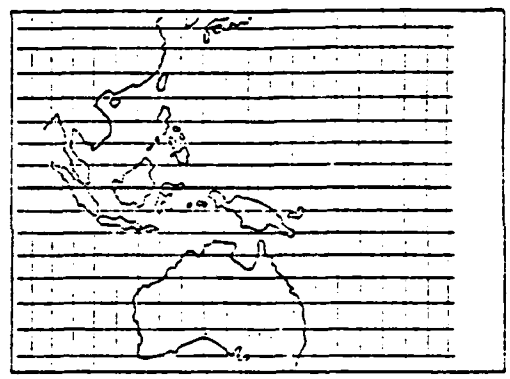
2) Partially enlarged picture



3) Polarstereo-projected picture



4) Mercator-projected picture



5) Seven-sectorized pictures

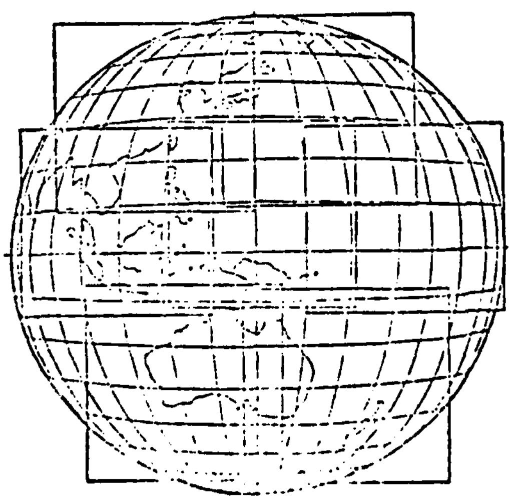


FIGURE E-1. Picture Output Format

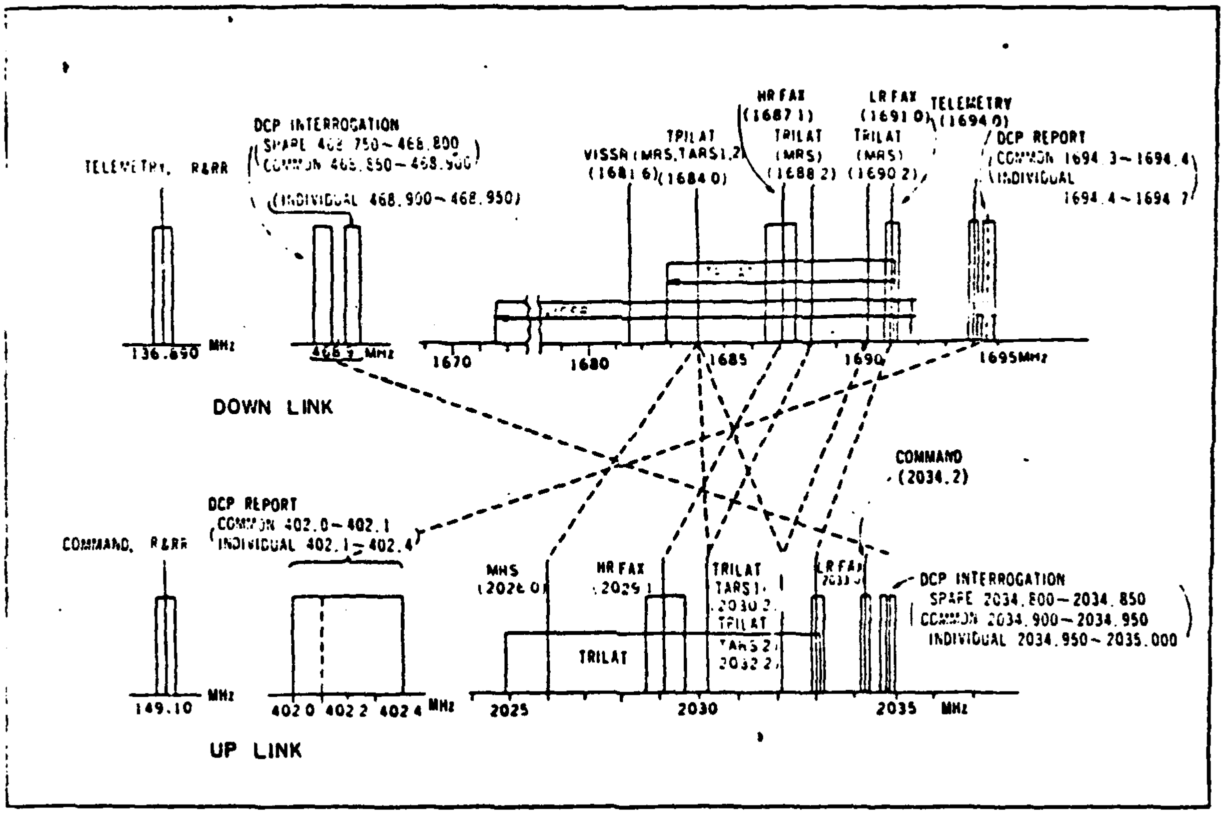


FIGURE E-2. Space-to-earth communications frequency allocation

Characteristics of VISSR

Wave length	Vis: 0.5-0.75 μm IR: 10.5-12.5 μm
Resolution at the sub-satellite point	Vis: 1.25 km IR: 5.0 km
Instantaneous field of view	Vis: 35 x 31 μrad IR: 140 x 140 μrad
Scan step angle	125 μrad (north-south scanning)
Temperature accuracy	0.5°K or less (when observing object 300°K) 1.5°K or less (when observing object 200°K)
Number of scan lines	Vis: 2500 x 4 IR: 2500
Frame time	27.5 minutes (including 2.5 mins for mirror retrace)
Power consumption	22.5 W
Weight	71 kg (including 5.9 kg of electronics)
Aperture	40.6 cm in diameter
Focal length	291.3 cm
Gray levels	Vis: 64 (6 bits) IR: 256 (8 bits)
Main carrier bandwidth	

Data utilization stations

At MDUS and SDUS facsimile signals are received and cloud images are reproduced to be used for weather prediction and investigation.

The major characteristics and specifications are summarized as follow:

Receiver	MDUS	SDUS
Receiving frequency and modulation	1687.1 MHz FM-FM	1691.1 MHz AM-FM
Bandwidth[1]	1 MHz	26/260 kHz
RF amplifier	Parametric amplifier	Solid state amplifier
G/T including antenna performance	10 dB/^{o}K	2 dB/^{o}K
Antenna[2]		
Type	Parabolic 4.0 m in diameter	Parabolic 2.5 m in diameter
Gain and beam width	34.8 dB 3.0 degrees	30.7 dB 4.8 degrees
Recorder[3]		
Film size	602 x 479 mm	220 x 220 mm
Recording system	Photo-type (Laser beam recording)	Photo-type (electro-static type also applicable)
Index of cooperation	2000	268
Line intensity	10.42 lines/mm	3.83 lines/mm
Drum diameter	192 mm	70 mm
Drum rotating rate	400 rpm	240 rpm
Receiving time	12 mins/picture	3.5 mins/picture (for 1 sectorized picture)

1 Bandwidth of LR FAX signal has been coordinated to be 26 kHz at the coordinating meeting among geostationary meteorological satellite operators; however, to meet ITU radio regulations, operation may be made with 260 kHz bandwidth. Accordingly, it is recommended that users install receiver sets which can cope with this two-way situation.

2 The spacecraft will be kept within 1^{o} of the nominal position so that no tracking mechanism of antenna or antenna positioning readjustment is required, although, due to the limit of the station-keeping propellant toward the end of the lifetime, the spacecraft might fluctuate more than 1^{o}.

3 FAX radio signals are products of D/A conversion from 64 gray-leveled digital signals, and HR and LR FAX contain 32 and 16 gray reference scales, respectively. Reproduction of picture gray levels at DUS depends mainly upon recorders used. Electrostatic type recorder may reproduce up to six gray levels; photo type recorder may reproduce up to sixteen.

GMS PRODUCTS

Table E-1. Primary Data (Cloud Imageries; output of on-line computer processing

Type of data	Region and scale of imageries	Effective picture size	Spacial resolution at sub-satellite point	Output time	Data distribution
Full-disc pictures	Full disc imageries of GMS coverage with gridding and coast lines See 1).	558x457 mm	Vis: 2.5 km IR: 5.0 km	Vis: 0,3,6,(9),(21) Z IR: 0,3,6,9,12,16,18,21Z ( ):not available in winter seasons For detailed schedule see 6).	To JMA HQ via microwave channels To international users through GMS HR-FAX transmission
Partially enlarged pictures of Japan and its vicinity region	15°N to 50°N and 115°E to 155°E with gridding and coast lines (1:7 to 1:11 million) See 2).		Vis: 1.25 km IR: 5.0 km	Vis: 0,3,6 Z IR: 9,12,16,18,21 Z	To JMA HQ only
Polarstereo-projected pictures*	Corresponds to Asia-Pacific synoptic chart (northern hemisphere), with gridding and coast lines (1:20 million at 60°N). See 3).			Vis: 0,6 Z IR: 0,6,12,18 Z (Available approx. 1h after the above observation time)	To JMA HQ only
Mercator-projected pictures*	36°N to 36°S, with gridding and coast lines (1:20 million at 22.5°) Not available when special observation are made. See 4).			IR: 0,6,12,18 Z For detailed schedule see 6).	To international users through GMS HR-FAX transmission
Seven-sectorized pictures	A full disc picture is divided into seven portions and the seven pictures are output in series with gridding and coast lines. See 5).		Vis: 4 km IR: 6 to 7 km	Vis: 0,3,6,(9),(21) Z IR: (9),12,16,18,(21) Z ( ):either Vis or IR pictures will be transmitted For detailed schedule see 6).	To international users through GMS LR-FAX transmission

* JMA Hq only

GMS PRODUCTS

Table E-2. Secondary Products (data derived from cloud image data; output of batch computer processing)

Type of data	Region of interest	Description	Output time	Accuracy of data	Data distribution
Neph-analysis chart	1:20 million stereographic chart (same as Asia-Pacific synoptic chart). Region is; N limit: a line on which elevation angle to see GMS is 30° S limit: 5°N E limit: 120°E) approx. W limit: 100°E)	Identification of specific clouds, cloud-top height, and growth and moves of clouds. Identification of sea-ice and fog. comments for weather forecast.	4h18m after observation time of 0,6,12 Z and 5h after that of 18 Z.		To domestic and international users through JMA's weather facsimile broadcast in short-wave "JMH"
Wind vector data	Region in which elevation angle to see GMS in greater than 35° (50°N to 50°S at 140°E, and 90°E to 170°W at the equator)	Two or three wind vector data derived from cloud tracking in a region of 5° in longitude and latitude (ocean region only)	Approx. 4h after observation time of 0,12 Z	3 m/s at the sub-satellite point	To JMA HQ and international weather services through GTS in a digital form of FM88-VI EXT. 7)
Radiated sea-surface temperature	do	Mean sea-surface temperature over 10 days and a month of each one degree in longitude and latitude	Every 10 days and monthly (monthly data will not be output to GTS.)	2°C or better	To JMA HQ and international weather services through GTS in a digital form of FM88-VI EXT. 8)
Cloud amount distribution	do	Mean cloud amount over 5 days and a month (35 day in August only) in a region of 1° in longitude and latitude (ocean region only) Cloud amount distribution is displayed in charts in the form of equi-distribution amount contour for total cloud, high and low altitude cloud	Every 5 days and monthly		To JMA HQ in the form of drawings

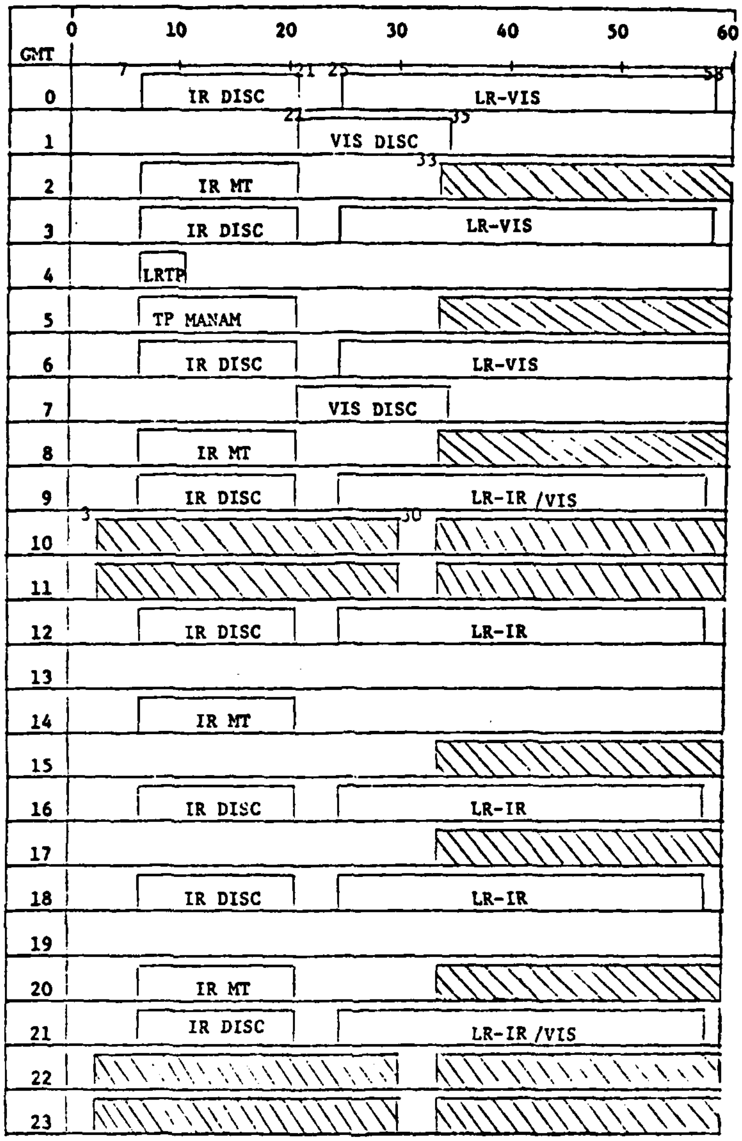


FIGURE E-3. Facsimile Transmission Schedule

: VISSR Observation

VIS: Visible
IR: Infrared
Disc: Full Disc
LR: Low Resolution Facsimile

MT: Mercator
TP: Test Pattern
MANAM: Manual Amendment

Observations

Wind observations and calculation will be made twice a day. One observation produces four to eight bulletins of data and one bulletin is made of 70 groups (one group corresponds to a region of $10^{o} \times 10^{o}$). 2,000 characters are contained in a bulletin at a maximum.

At a time (every 10 days) 25 bulletins of data will be transmitted at maximum. One bulletin contains 270 groups (grid points), so 7,000 grid point data are transmitted at a time. 2,000 characters are contained in a bulletin at maximum.

The Meteorological Satellite Center publishes wind vector data, radiated sea-surface temperature data, cloud amount distribution data, cloud-top height data, nephanalysis charts, and space environment monitor data regularly.

Wind vector data and sea surface temperature data were recorded on magnetic tapes that were sent to the Level II-b Space-based and Special Observing Data Centre in Sweden for FGGE.

Use of Various Products

The Meteorological Satellite Center (JMA) archives various GMS products and international users may retrieve them on a cost-reimbursable basis. The archived products contain:

(a) Cloud pictures

(b) Computer-compatible tapes of full resolution cloud images

Interested Users are requested to contact:

Meteorological Information Center
Japan Weather Association (Nihon Kisho Kyokai)
4-5 Kojimachi, Chiyoda-ku, Tokyo 102
JAPAN

More detailed information is available from:

Dr. Y. Sekiguchi
Director, Planning Division
Japan Meteorological Agency
1-3-4 Otemachi, Chiyoda-ku, Tokyo 100
JAPAN